EDF Title: **TSF-26 PM2A HALF-TANK LIFTING LUGS DESIGN**	
Project No.: 2000-096	Project Title: OU 1-10, TSF-26 REMEDIATION
Project Specific Activity: PM2A HALF TANK LIFTING LUGS DESIGN AND CALCULATIONS	

Problem Statement:

Design lifting lugs with tank reinforcing pads that can be welded to the PM-2A top and bottom half tanks and used to attach the rigging to lift the half tanks.

Summary of Conclusions:

The design chosen is to weld ½ inch steel plates 2 ft long and 1 ft high to the outer surface of the tank at the locations of the reinforcement ribs where the rigging is to be attached and to weld 3/4 inch lugs to the plate to attach the rigging. A finite element structural analysis model of this design shows that the stresses in the tank wall are below 1/3 of the yield strength and the factor of safety of 3 as required by the DOE-STD-1090 reference to ASME B30.20-1.2.2 for "*Below the Hook Lifting Devices*" is met.

REVIEW AND APPROVAL SIGNATURES:

	R/A	TYPED NAME/ORGANIZATION	SIGNATURE	DATE
PREPARED BY:		Lowell Magleby	Herbert L Magleby	12/3/03
CHECKED BY:		KEVIN SHABER	[signature]	12/3/03
INDEPENDENT REVIEWER				
APPROVAL:		GARY MECHAM	Gary Mecham	12/3/03

Distribution:

Registered Professional Engineer's Stamp (if required)

REGISTERED PROFESSIONAL ENGINEER
Herbert L Magleby
2494
12/3/03
STATE OF IDAHO
HERBERT L. MAGLEBY

PROBLEM STATEMENT:

TSF-26 Site Remediation Operations require the cutting and removal of the PM2A Tanks [V-13 (East Tank) and V-14 (West Tank)] halves in conjunction with waste removal operations.

Design lifting lugs with tank reinforcing pads that can we welded to the PM-2A top and bottom half tanks and used to attach the rigging to lift the half tanks. This is an alternate method

The half tanks each weigh 33,425 lbs. The half tanks are to be lifted with a mobile crane using a single hook. The tanks are to be rigged near the two end internal rib stiffeners of the tank each located about 11 feet from their respective ends. The rigging will use a spreader bar so that the lifting points will be directly above the rigging location at the stiffeners. The length of the rigging from the spreader bar to the tank will be of a length so that the angle of the rigging from the lugs welded to each side of the tank, about 12 ½ feet apart, to the attachment points on the spreader will be about 35° from vertical.

ASSUMPTIONS:

The Assumptions utilized in the performance of these calculations are outlined below:

- Thickness of the PM2A Tank walls to be 5/8"
- Thickness of PM2A Tank Exterior TAR Coating was confirmed to be 1/16" and NOT the previously reported 1'2" to 1" thickness range.
- Calculated Weight of the PM2A Tank Half is 33,425 pounds

REFERENCES:

EDF-0960012 Rev.2
DOE-ID Order 440C
DOE-STD-1090-2001
ASME B30.20a-2001

ACCEPTANCE CRITERIA:

The stresses in the tank wall will be less than 1/3 of yield stress to meet the intent of the DOE-STD-1090 reference to ASMEB30.20a. The design of the pads to be welded to the tank wall and the lifting lugs will have a factor of safety of 3 to be in compliance with the DOE-STD-1090 reference to ASMEB30.20a.

DESCRIPTION OF DESIGN:

The design is shown on Drawing M-6 included in the design submittal and is shown on the attached sketch. The design is to weld a ½ inch steel plate 2 ft long by 1 ft high to the outside surface of the half tanks at the location of the rigging points at the end stiffeners located about 11 feet from thier respective ends. Lifting lugs fabricated from 3/4 inch steel plate are welded to the ½ inch steel plate at the rigging attachment plates. The lifting lugs are sized for attaching 1 inch shackles.

DESCRIPTION OF ANALYSIS:

A three dimensional finite element model was made of the plate attachment to the tank outer surface using the RISA 3D structural analysis program. The support of the plate by the tank wall was approximated by modeling a section of the tank wall one foot greater than the size of the plate at each side and fixing the outer edges. Flat plates were used in the model to simplify the modeling but curved plates would be expected to be stronger; therefore, the model is considered to be conservative. The model is rather coarse in that the number of flat plates used to formulate the model is not large. However, care was taken in formulating the model to assure that there were sufficient plates so that parts were connected by at least the node points. The model is shown in the attachment titled RISA 3D Analysis.

The design is the same for the top half tank and the bottom half tank. However, the direction of the load is away from the free edge for lifting the top half tank and towards the free edge for the bottom half tank. Analyses were made with the force in both directions.

The lifting lug was analyzed manually as was done in the design of the lugs for the spreader bar. See the EDF 096-012 included in the Design Submittal. The analyses for the lug for this application are included in the Attachment Lifting Lug Analysis.

ANALYSIS RESULTS:

The results of the analyses are shown in the attached table, Results of Analyses of Half Tank Lifting Lugs for PM-2A Rigging. The stresses were higher for the bottom half tank with the lifting force towards the free edge. The results are in the table for this case. The complete RISA 3D results for both cases are included in the attached RISA 3D Analysis. The RISA 3D results given in the results table only gives the stresses at the center of the small plates used to formulate the model. The highest stresses usually occur at the edges of the small plates. The contour plots of the results provided by RISA 3D show extrapolation of the stresses to all points in the model. The stresses for the half tank wall and the ½ inch plate welded to the half tank were taken from the counter plots. Narrow ½ plates were used to model the welds between the half thank wall and the ½ inch plate and the stress at the center of these narrow plates from the results table were used for the welds.

The result is the table showing that the acceptance criteria are met and the design is acceptable.

Results of Analyses of Half Tank Lifting Lugs for PM-2A Rigging

PART	*ACCEPTANCE REFERENCE*	*SPECIFIED ACCEPTANCE*	*BASIS FOR SAFETY FACTOR*	*CALCULATE STRESS*	*SAFETY FACTOR*
Half tank wall	Intent of DOE-STD-1090 14.2.1 which invokes ASMEb30,20-1.2.2	Safety factor of three based on yield strength	$F_y = 36$ ksi	Von Mises Stress = 11.7 ksi	3.08
½ in. plate	DOE-STD-1090 14.2.1 which invokes ASMEb30,20-1.2.2	Safety factor of three based on yield strength	$F_y = 36$ ksi	Von Mises Stress = 11.7 ksi	3.08
Weld of ½ in plate to half tank wall	*AISC Manual of Steel Construction J2.2	0.3 F_u	21.0 ksi	Max shear stress = 3.63 ksi	5.78
Lifting lug Tension stress	DOE-STD-1090 14.2.1 which invokes ASMEb30,20-1.2.2	Safety factor of three based on yield strength	$F_y = 36$ ksi	3.04 ksi	11.84
Lifting lug bearing stress	*AISC Manual of Steel Construction J3.7	$F_p = L_eF_u/2d$	51.6 ksi	12.09 ksi	4.27
Lifting lug fillet weld	*AISC Manual of Steel Construction J2.2	0.3 F_u	21.0 ksi	3.06	6.86

* DOE-STD-1090 Section 14.2.1 invokes ASME B30.20-1.2.2 which specifies a safety factor of 3 based on yield stress. The allowable values for the stresses for the items marked with an asterisks are not usually based on the yield stress; therefore, the allowable values for these stresses from the AISC Manual of Steel Construction were used but the requirement used in the design was that the safety factor based on these stress must be greater than 3.

INEEL BBWI RFP-394 RD/RA Work Plan for WAG 1-10 ==> Crane Lifting / Loading Calculations

WAG 1-10 Sites TSF-26, TSF-03, and WRRTF-01

INTREPID prepared Revision 0 dated - 13-Jan-2003, by DJ Kenoyer, Checked by SD Dustin

1 *Revision 1, 24-Feb-03, by DJ Kenoyer*

2 *Revision 2, 15-Jul-03, by DJ Kenoyer*

3 *100% Rev 1, 28-Jul-03, by DJ Kenoyer / Changed Tank Thickness to be MORE Conservative to 1/4" from 3/16"*

4 *Draft FINAL, 29-Sep-03 by DJ Kenoyer / Changed Tank Thickness from 1/4" to the 1/2" found during September 2003 Tank Sampling efforts by BBWI*

5 *07-Nov-03 by DJ Kenoyer / Tank Exterior Tar Coating Thickness from 1/2" to 1" found during September 2003 Tank Sampling efforts by BBWI*

6 *20-Nov-03 by DJ Kenoyer / Tank Exterior Tar Coating Thickness 1/16" confirmed by BBWI ==> NOT 1/2" to 1" as reported earlier*

7 *01-Dec-03 by DJ Kenoyer / Tank Steel thickness 5/8" confirmed by BBWI ==> NOT 1/2" as reported earlier [Revision 4]*

Original Configuration

Description	diameter (lineal feet)	length	depth	Area (square feet)	Thickness (inches)	Unit (lbs/sf)	Weight: Tank (lbs)	Weight: Added (lbs)	Weight: Total (lbs)	Half-PM2A (lbs)	
Weight Calculations											
7					5/8	25.60	61,575	4,310	65,885	32,943	7
7 Specific Weight of "TAR"	72 lbs per cubic foot				0.06	0.38	902	63	965	483	6
										33,425	7 & 6
					1/2	20.40	49,068	3,435	52,502	26,251	4
Specific Weight of "TAR"	72 lbs per cubic foot				0.06	0.38	902	63	965	483	6
										26,734	4 & 6
PM2A Tank	12.5	55.0		2,405.3	3/8	15.30	36,801	2,576	39,377	19,688	
					5/16	12.80	30,788	2,155	32,943	16,471	
Assume Tank Ribs and Manways ==>	7.0% Added Weight				1/4	10.20	24,534	1,717	26,251	13,126	3
					3/16	7.65	18,400	1,288	19,688	9,844	
					1/8	5.10	12,267	859	13,126	6,563	

Description	width (lineal feet)	length (lineal feet)	height (lineal feet)	Length (lineal feet)	Width (lineal feet)	Unit (lbs/lf)	Weight: THA (lbs)	Weight: Added (lbs)	Weight: Total (lbs)
2 **Weight Calculations for RUBB THA Shelter**									
THA 8 Meter	26.2	65.0		40.0	26.2		5,050		5,050
				25.0		71.00		1,775	1,775
	Percentage Contingency for Added Weight Associated with Lifting System ==>							5.0%	350
									7,175
2 **Weight Calculations for RUBB Special Shelter**									
THA 22'0" Walls	16.0	35.0		35.0	16.0	8.0	4,480		4,500
	Percentage Contingency for Added Weight Associated with Lifting System ==>							5.0%	230
									4,730

Description		width (lineal feet)	length (lineal feet)	thickness (lineal feet)	Volume (cubic feet)	Unit (lbs/cf)	Weight: Precast (lbs)	Weight: Added (lbs)	Weight: Total (lbs)
2 **Weight Calculations for Precast "C" Section Shielding Concrete**									
Sides	2	6.0	9.8	0.75	87.8	145.0	12,724		12,724
End	1	6.0	13.8	0.75	62.2	145.0	9,024		9,024
			Percentage Contingency for Added Steel Reinforcing ==>					4.5%	980
									22,728

Technical Specifications for Grove Mobile Hydraulic Crane GMK5240 [240 ton crane]

Boom Extension (h-lineal feet)	(h-lineal feet)	*Boom Angle* (degrees)	*Lift Capacity* (lbs)	*Whole Tank* 52,502 (lbs) Percent Lift Capacity	*Half Tank* 26,251 / 26,734 (4 & 6) (lbs)
105.0	**80.0**	40.4	53,000	99.1%	49.5%
121.0	**100.0**	34.3	36,000	145.8%	72.9%
136.0	**110.0**	36.0	32,200		
151.0	**120.0**	37.4	24,800		

Distance from C/L Crane to C/L of Load ==> (h-lineal feet)

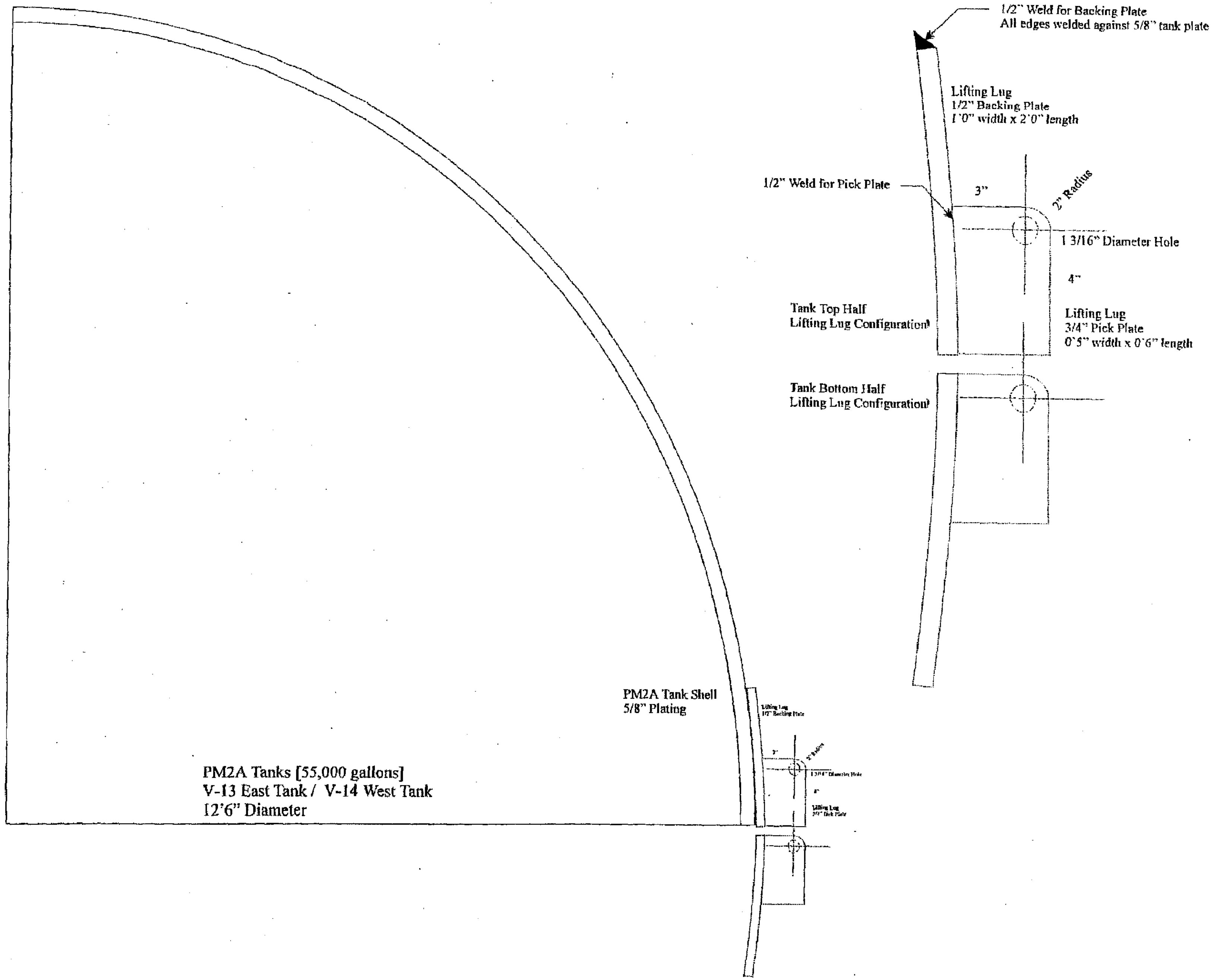
Grove 5240 Counterweights	154,300 pounds
Outrigger Status - Extensions	100% 27'3" Spread
Crane Rotation Status	360 degrees

		Horizontal Distance - Crane to Tank			*Lift Capacity*	*Percent Loading*	
V-13	**East Tank**	**80.0**	**h-lineal feet**		**53,000**	**49.5%**	4
V-14	**West Tank**	**100.0**	**h-lineal feet**		**36,000**	**72.9%**	4
RUBB THA	**26.2' x 65.0**	**110.0**	**h-lineal feet**	**7,175**	**32,200**	**22.3%**	4
Precast "C" Shape		**110.0**	**h-lineal feet**	**22,728**	**32,200**	**70.6%**	

Long High Capacity Trailers Available ==> 2003 Fontaine Specialized TDFT Telescopic Step, Drop Decl Extendable
102" wide / 48'-69' deck / 80,000 lbs capacity

		Horizontal Distance - Crane to Tank			*Lift Capacity*	*Percent Loading*	
V-13	**East Tank**	**80.0**	**h-lineal feet**		**53,000**	**50.4%**	4 & 6
V-14	**West Tank**	**100.0**	**h-lineal feet**		**36,000**	**74.3%**	4 & 6
RUBB THA	**26.2' x 65.0**	**110.0**	**h-lineal feet**	**7,175**	**32,200**	**22.3%**	
Precast "C" Shape		**110.0**	**h-lineal feet**	**22,728**	**32,200**	**70.6%**	

		Horizontal Distance - Crane to Tank			*Lift Capacity*	*Percent Loading*	
V-13	**East Tank**	**80.0**	**h-lineal feet**		**53,000**	**63.1%**	7 & 6
V-14	**West Tank**	**100.0**	**h-lineal feet**		**36,000**	**92.8%**	7 & 6
RUBB THA	**26.2' x 65.0**	**110.0**	**h-lineal feet**	**7,175**	**32,200**	**22.3%**	
Precast "C" Shape		**110.0**	**h-lineal feet**	**22,728**	**32,200**	**70.6%**	

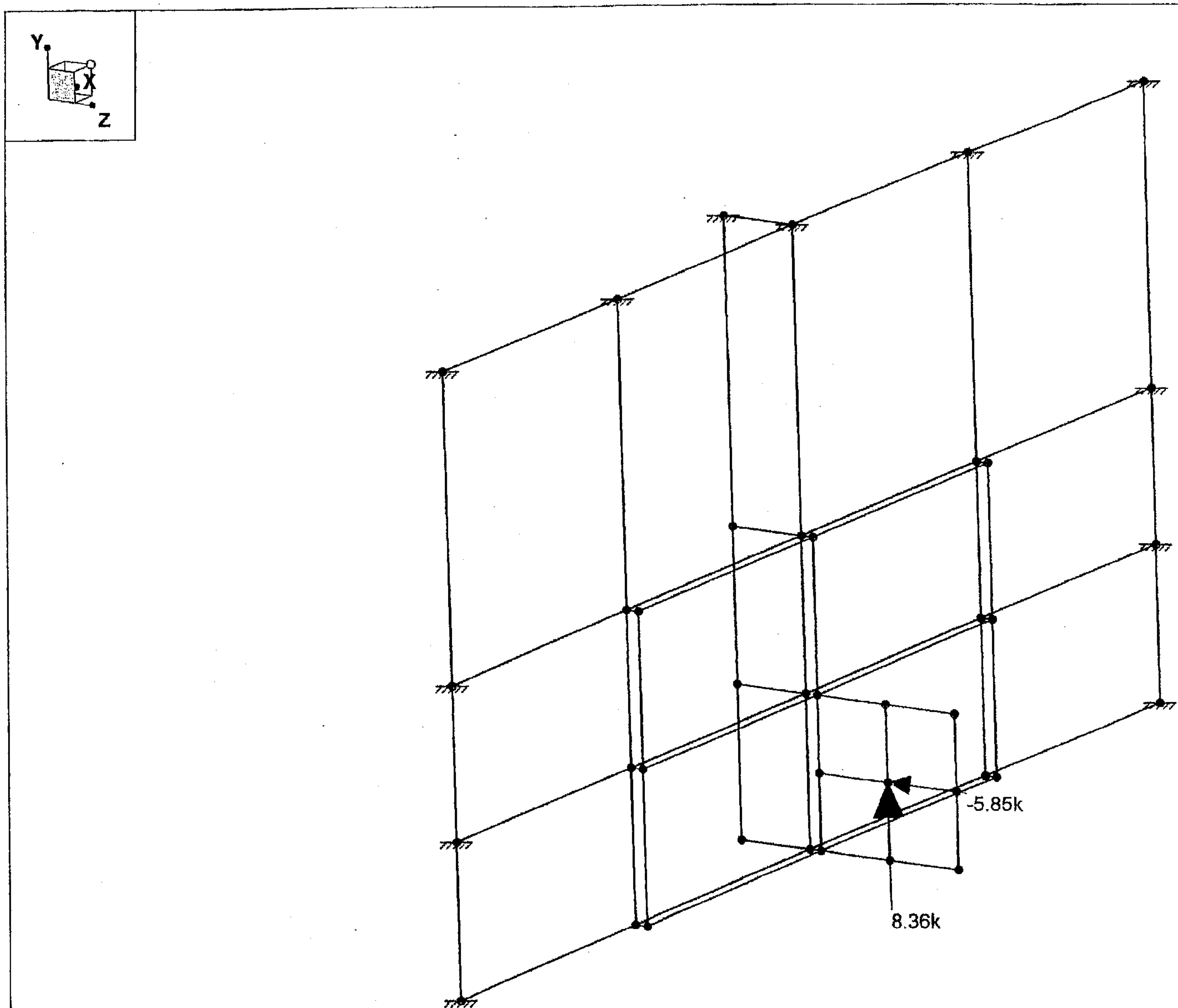


PM2A Tanks [55,000 gallons]
V-13 East Tank / V-14 West Tank
12'6" Diameter
PM2A Tank Shell
5/8" Plating
1/2" Weld for Backing Plate
All edges welded against 5/8" tank plate
Lifting Lug
1/2" Backing Plate
1'0" width x 2'0" length
1/2" Weld for Pick Plate
3"
2" Radius
1 3/16" Diameter Hole
4"
Tank Top Half
Lifting Lug Configuration
Lifting Lug
3/4" Pick Plate
0'5" width x 0'6" length
Tank Bottom Half
Lifting Lug Configuration

RISA 35 ANALYSIS

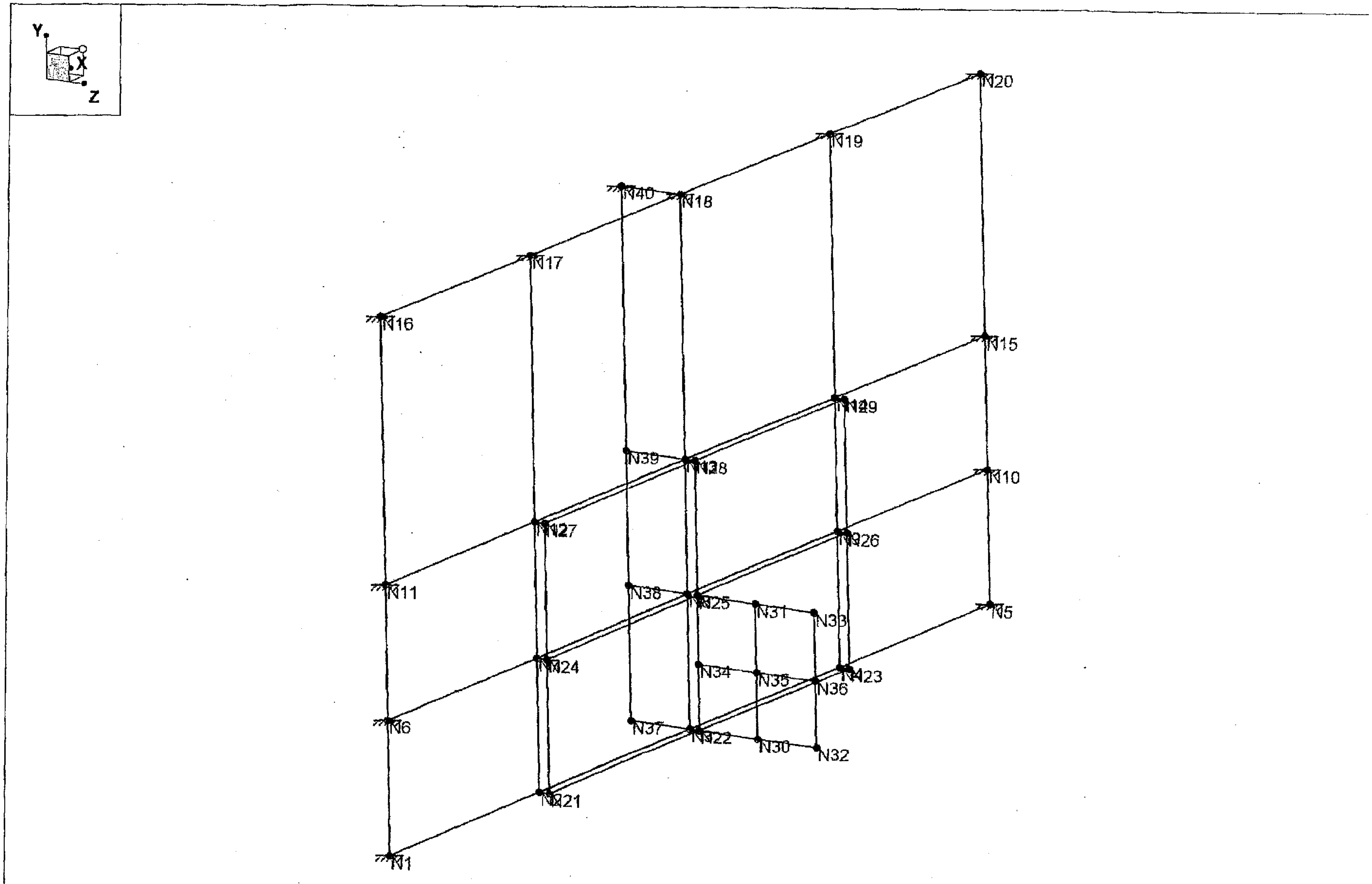
RISA 3D ANALYSIS

UPPER HALF TANK

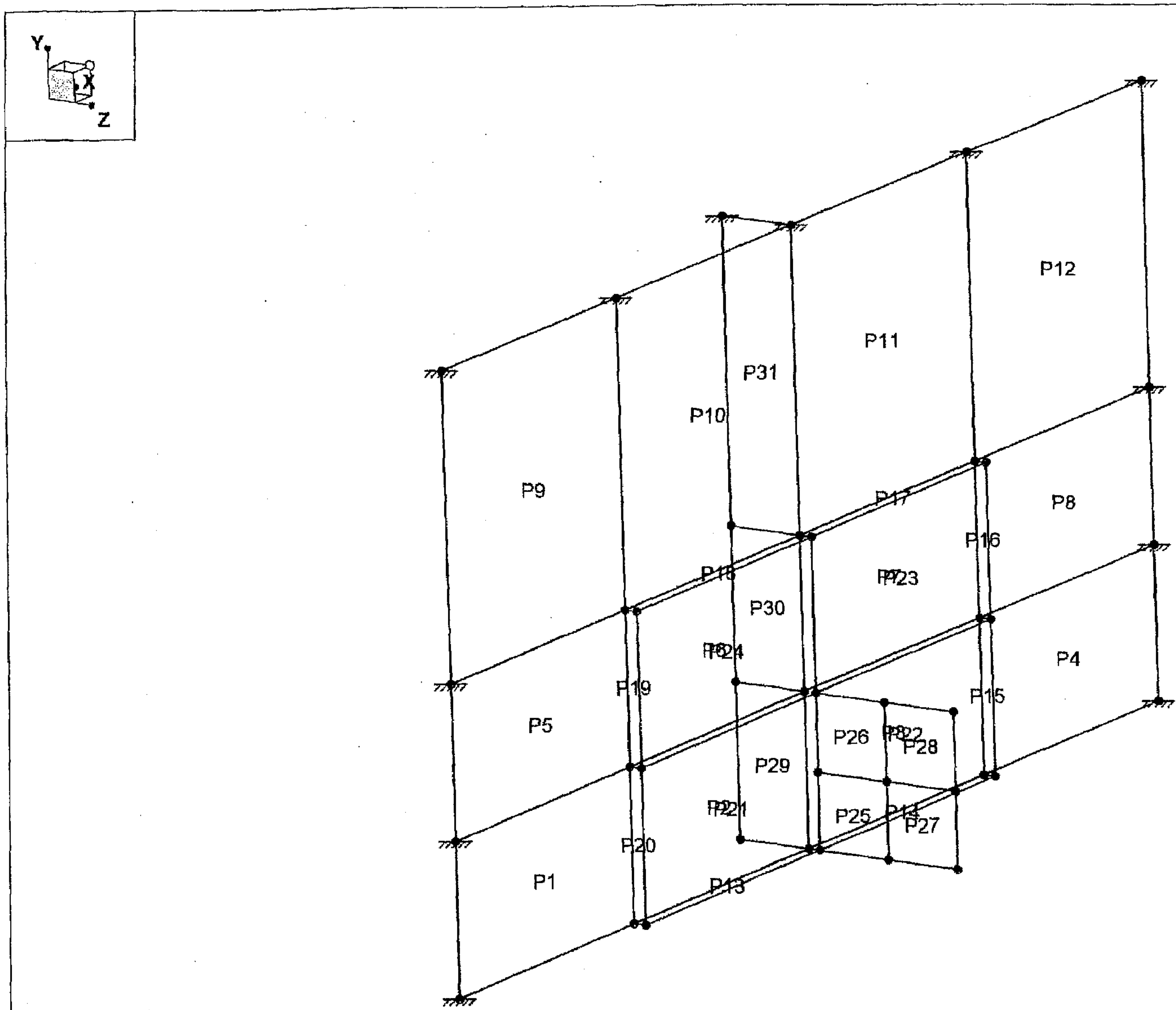


Loads: BLC 2,
Results for LC 2, Upper Half 5/8 wall

Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:00 PM
		Tank lift pad .625 wall.r3d



Results for LC 2, Upper Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:03 PM
		Tank lift pad .625 wall.r3d



Results for LC 2, Upper Half 5/8 wall	
Intrepid Technology and Resources, ..	PM-2A Tank Lug
ITR	

December 2, 2003
6:05 PM
Tank lift pad .625 wall.r3d

Joint Coordinates

Joint Label	X Coordinate (in)	Y Coordinate (in)	Z Coordinate (in)	Joint Temperature (F)	Detach from Diaphragm
N1	0	0	0	0	No
N2	12	0	0	0	No
N3	24	0	0	0	No
N4	36	0	0	0	No
N5	48	0	0	0	No
N6	0	6	0	0	No
N7	12	6	0	0	No
N8	24	6	0	0	No
N9	36	6	0	0	No
N10	48	6	0	0	No
N11	0	12	0	0	No
N12	12	12	0	0	No
N13	24	12	0	0	No
N14	36	12	0	0	No
N15	48	12	0	0	No
N16	0	24	0	0	No
N17	12	24	0	0	No
N18	24	24	0	0	No
N19	36	24	0	0	No
N20	48	24	0	0	No
N21	12	0	.5	0	No
N22	24	0	.5	0	No
N23	36	0	.5	0	No
N24	12	6	.5	0	No
N25	24	6	.5	0	No
N26	36	6	.5	0	No
N27	12	12	.5	0	No
N28	24	12	.5	0	No
N29	36	12	.5	0	No
N30	24	0	3.5	0	No
N31	24	6	3.5	0	No
N32	24	0	6.5	0	No
N33	24	6	6.5	0	No
N34	24	3	.5	0	No
N35	24	3	3.5	0	No
N36	24	3	6.5	0	No
N37	24	0	-3	0	No
N38	24	6	-3	0	No
N39	24	12	-3	0	No
N40	24	24	-3	0	No

Plate/Shell Elements

Plate Label	A Joint	B Joint	C Joint	D Joint	Material Set	Thickness (in)	Stress Location 'R'	'S'	Inactive?
P1	N1	N6	N7	N2	STL	.625	0	0	
P2	N2	N7	N8	N3	STL	.625	0	0	
P3	N3	N8	N9	N4	STL	.625	0	0	
P4	N4	N9	N10	N5	STL	.625	0	0	
P5	N6	N11	N12	N7	STL	.625	0	0	
P6	N7	N12	N13	N8	STL	.625	0	0	
P7	N8	N13	N14	N9	STL	.625	0	0	
P8	N9	N14	N15	N10	STL	.625	0	0	
P9	N11	N16	N17	N12	STL	.625	0	0	
P10	N12	N17	N18	N13	STL	.625	0	0	
P11	N13	N18	N19	N14	STL	.625	0	0	
P12	N14	N19	N20	N15	STL	.625	0	0	
P13	N21	N2	N3	N22	STL	.625	0	0	
P14	N22	N3	N4	N23	STL	.625	0	0	
P15	N23	N4	N9	N26	STL	.625	0	0	
P16	N26	N9	N14	N29	STL	.625	0	0	
P17	N28	N13	N14	N29	STL	.625	0	0	
P18	N27	N12	N13	N28	STL	.625	0	0	
P19	N24	N7	N12	N27	STL	.625	0	0	
P20	N21	N2	N7	N24	STL	.625	0	0	
P21	N21	N22	N25	N24	STL	.625	0	0	
P22	N22	N23	N26	N25	STL	.625	0	0	
P23	N25	N26	N29	N28	STL	.625	0	0	
P24	N24	N25	N28	N27	STL	.625	0	0	
P25	N30	N22	N34	N35	STL	.75	0	0	
P26	N35	N34	N25	N31	STL	.75	0	0	
P27	N32	N30	N35	N36	STL	.75	0	0	
P28	N36	N35	N31	N33	STL	.75	0	0	
P29	N3	N37	N38	N8	STL	1	0	0	
P30	N8	N38	N39	N13	STL	1	0	0	
P31	N13	N39	N40	N18	STL	1	0	0	

Joint Loads/Enforced Displacements, Category : None, BLC 1 : Lower Half 5/8 wall

Joint Label	[L]oad,[M]ass,or [D]isplacement	Direction	Magnitude (k, k-in, in, rad, k*s^2/in)
N35	L	Y	-10.2
N35	L	Z	-5.85

Reactions, By Combination

LC	Joint Label	X Force (k)	Y Force (k)	Z Force (k)	X Moment (k-in)	Y Moment (k-in)	Z Moment (k-in)
2	N1	.919	.425	.449	.024	-2.887	0
2	N6	.831	-.311	.207	-.101	-1.224	0
2	N11	.83	-.251	.002	-.125	-.559	0
2	N16	.215	-.174	.048	-.238	-.262	0
2	N17	-.01	-.195	.158	-1.434	-.158	0
2	N18	0	11.849	-.498	-3.133	0	0
2	N40	0	-19.199	4.618	0	0	0
2	N19	.01	-.195	.158	-1.434	.158	0
2	N20	-.215	-.174	.048	-.238	.262	0
2	N15	-.83	-.251	.002	-.125	.559	0
2	N10	-.831	-.311	.207	-.101	1.224	0
2	N5	-.919	.425	.449	.024	2.887	0
2	Totals:	0	-8.36	5.85			
2	COG (in):	X: 24	Y: 3	Z: 3.5			

Plate/Shell Principal Stresses, By Combination

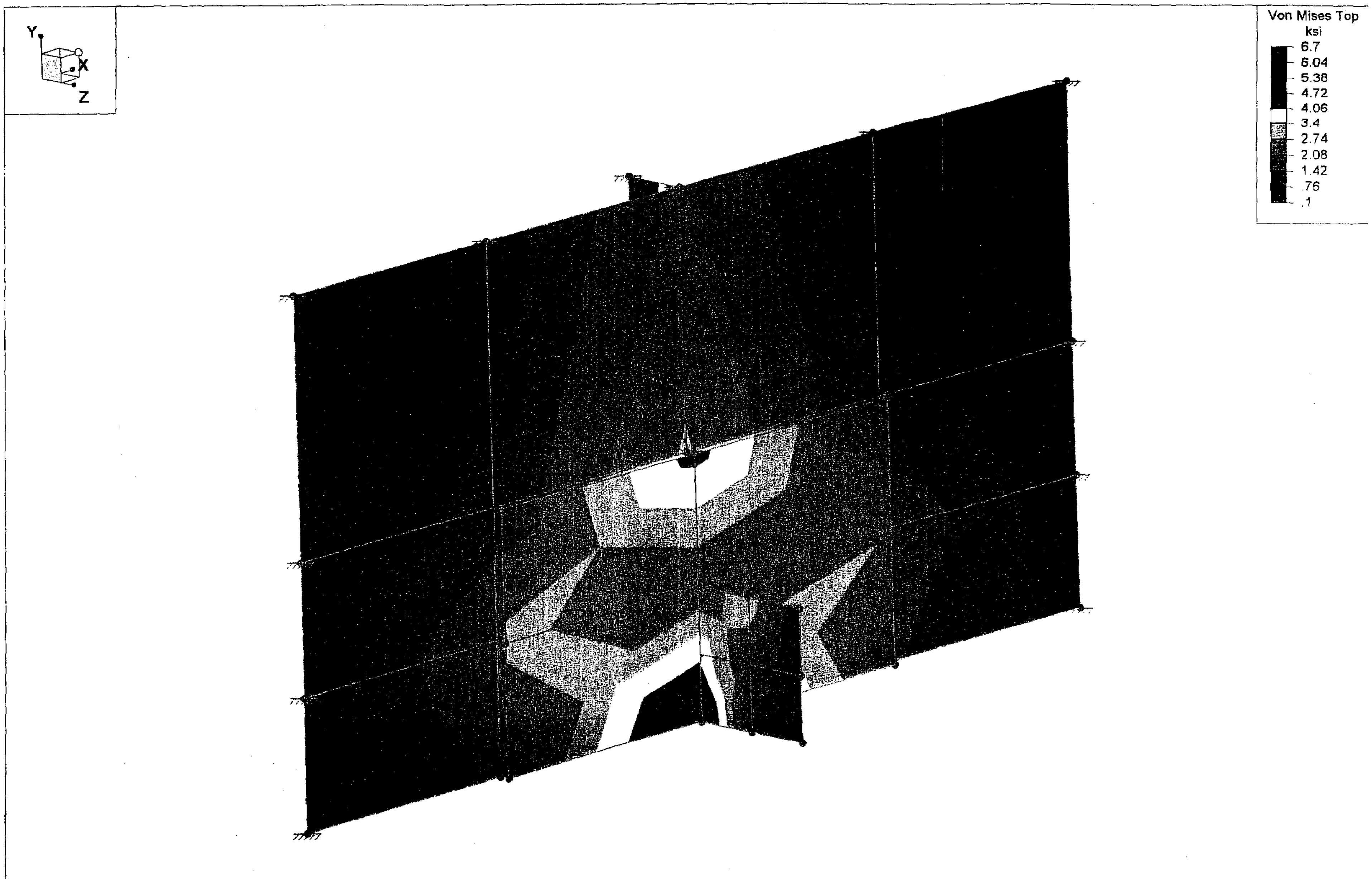
LC	Plate Label	Surface [T]op / [B]ottom	Sigma1 (ksi)	Sigma2 (ksi)	Tau Max (ksi)	Angle (radians)	Von Mises (ksi)
2	P1	T	.63	.054	.288	-.614	.605
		B	-.334	-1.225	.445	-.152	1.097
2	P2	T	-.319	-.632	.156	.705	.547
		B	1.33	.64	.345	.21	1.152
2	P3	T	-.319	-.632	.156	-.705	.547
		B	1.33	.64	.345	-.21	1.152
2	P4	T	.63	.054	.288	.614	.605
		B	-.334	-1.225	.445	.152	1.097
2	P5	T	.331	.053	.139	-.554	.308
		B	.06	-.882	.471	-.395	.914
2	P6	T	.194	-.211	.202	.325	.351
		B	1.114	.312	.401	.568	.995
2	P7	T	.194	-.211	.202	-.325	.351
		B	1.114	.312	.401	-.568	.995
2	P8	T	.331	.053	.139	.554	.308
		B	.06	-.882	.471	.395	.914
2	P9	T	.282	.083	.1	.707	.251
		B	-.124	-.415	.146	-.733	.369
2	P10	T	.458	.004	.227	.212	.456
		B	.098	-.523	.311	.243	.579
2	P11	T	.458	.004	.227	-.212	.456
		B	.098	-.523	.311	-.243	.579
2	P12	T	.282	.083	.1	-.707	.251
		B	-.124	-.415	.146	.733	.369
2	P13	T	-1.957	-7.15	2.597	.236	6.4
		B	6.693	1.539	2.577	-.197	6.072
2	P14	T	-1.957	-7.15	2.597	-.236	6.4
		B	6.693	1.539	2.577	.197	6.072
2	P15	T	-.766	-3.01	1.122	.126	2.71
		B	3.09	1.048	1.021	-.104	2.722
2	P16	T	-.875	-3.517	1.321	.026	3.171
		B	4.035	1.207	1.414	-.248	3.587
2	P17	T	5.353	1.472	1.941	.055	4.79
		B	-1.816	-6.048	2.116	-.134	5.375
2	P18	T	5.353	1.472	1.941	-.055	4.79
		B	-1.816	-6.048	2.116	.134	5.375
2	P19	T	4.035	1.207	1.414	-.248	3.587
		B	-.875	-3.517	1.321	.026	3.171
2	P20	T	3.09	1.048	1.021	-.104	2.722
		B	-.766	-3.01	1.122	.126	2.71
2	P21	T	.878	.403	.237	.152	.761
		B	-1.444	-2.078	.317	.367	1.844
2	P22	T	.878	.403	.237	-.152	.761
		B	-1.444	-2.078	.317	-.367	1.844
2	P23	T	.22	-.38	.3	.556	.525
		B	-.948	-2.172	.612	.782	1.886
2	P24	T	.22	-.38	.3	-.556	.525
		B	-.948	-2.172	.612	-.782	1.886
2	P25	T	1.588	-.428	1.008	-.539	1.84
		B	1.588	-.428	1.008	-.539	1.84
2	P26	T	.396	-5.282	2.839	-.739	5.491
		B	.396	-5.282	2.839	-.739	5.491
2	P27	T	.344	-.317	.331	-.77	.573
		B	.344	-.317	.331	-.77	.573
2	P28	T	.151	-.649	.4	.486	.736
		B	.151	-.649	.4	.486	.736

Plate/Shell Principal Stresses, By Combination, (continued)

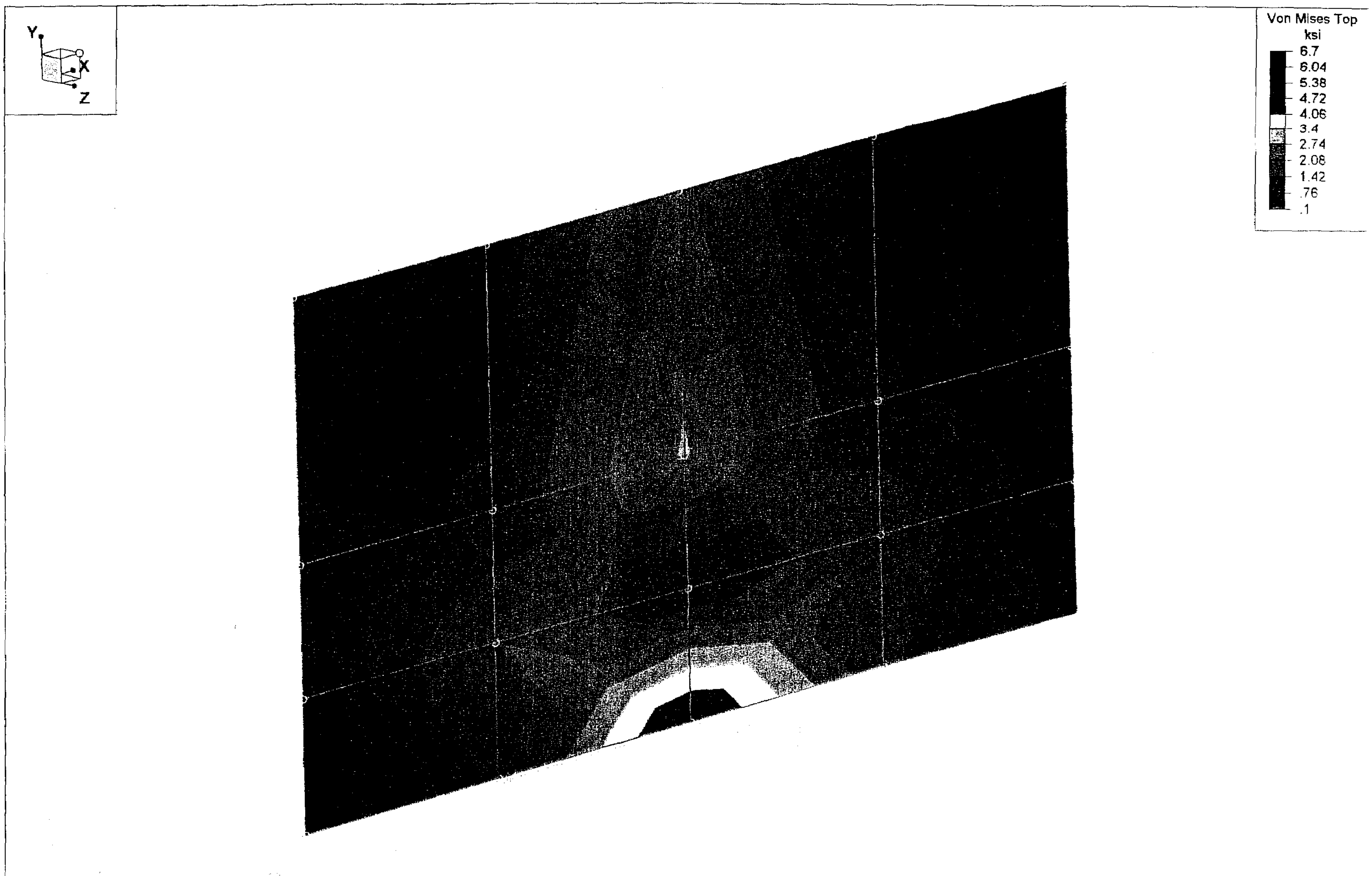
LC	Plate Label	Surface [T]op / [B]ottom	Sigma1 (ksi)	Sigma2 (ksi)	Tau Max (ksi)	Angle (radians)	Von Mises (ksi)
2	P29	T	.456	-.272	.364	.539	.637
		B	.456	-.272	.364	.539	.637
2	P30	T	.891	-1.324	1.108	.719	1.931
		B	.891	-1.324	1.108	.719	1.931
2	P31	T	.239	-2.981	1.61	.426	3.108
		B	.239	-2.981	1.61	.426	3.108

Plate/Shell Forces, By Combination

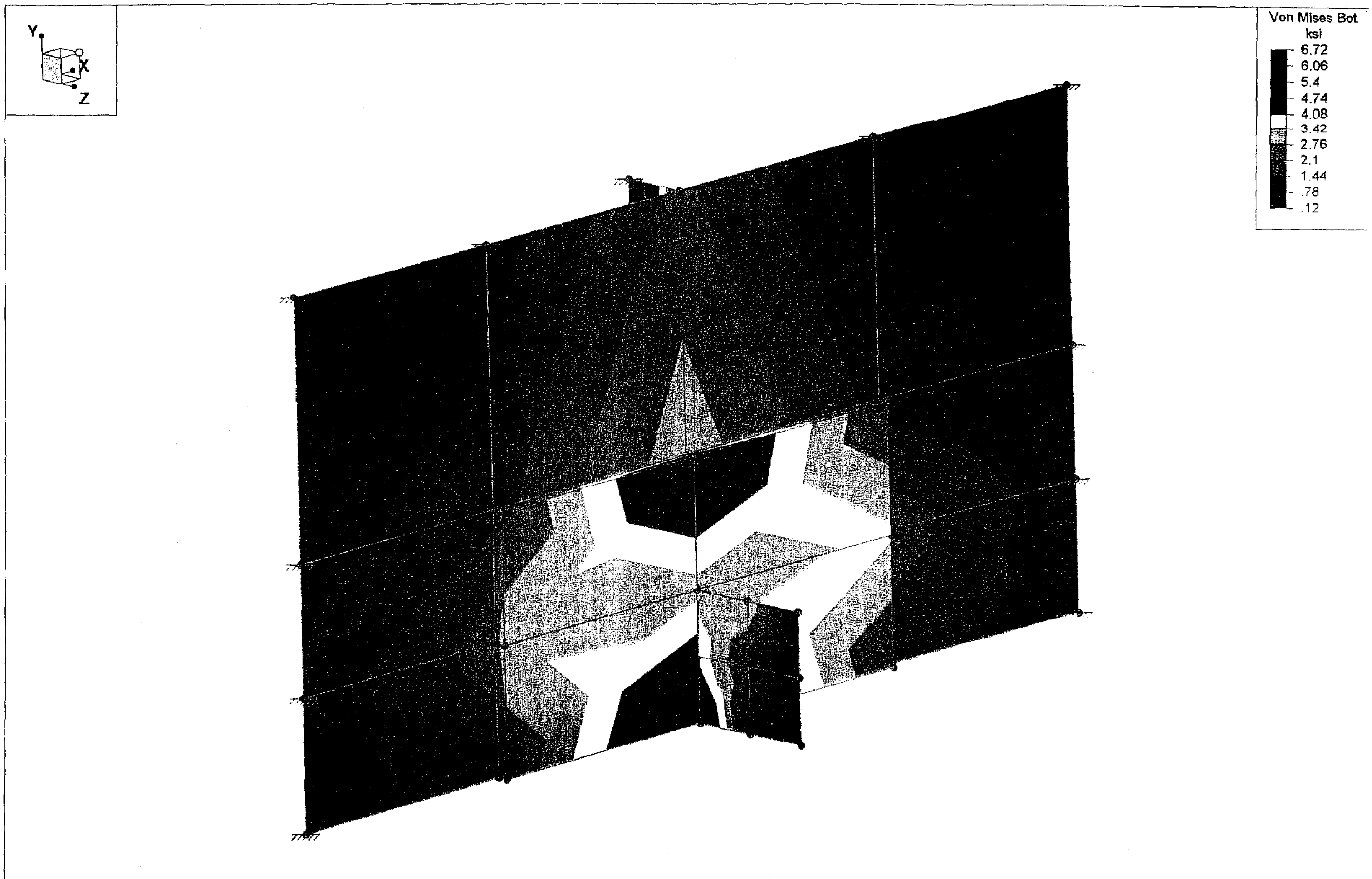
LC	Plate Label	Qx (k/in)	Qy (k/in)	Mx (k-in/in)	My (k-in/in)	Mxy (k-in/in)	Fx (k/in)	Fy (k/in)	Fxy (k/in)
2	P1	.004	.11	.02	.054	.013	-.034	-.239	.043
2	P2	.129	-.078	-.036	-.059	.01	.069	.25	.004
2	P3	.129	.078	-.036	-.059	-.01	.069	.25	-.004
2	P4	.004	-.11	.02	.054	-.013	-.034	-.239	-.043
2	P5	-.008	-.005	.007	.032	.015	.016	-.153	-.066
2	P6	-.119	-.007	-.013	-.034	.016	.218	.223	-.075
2	P7	-.119	.007	-.013	-.034	-.016	.218	.223	.075
2	P8	-.008	.005	.007	.032	-.015	.016	-.153	.066
2	P9	.006	.007	.015	.015	.008	-.018	-.037	-.015
2	P10	.032	-.002	.03	-.001	.008	-.015	.027	-.016
2	P11	.032	.002	.03	-.001	-.008	-.015	.027	.016
2	P12	.006	-.007	.015	.015	-.008	-.018	-.037	.015
2	P13	.066	-.006	-.435	-.129	-.006	-.116	-.157	-.678
2	P14	.066	.006	-.435	-.129	.006	-.116	-.157	.678
2	P15	.94	-.035	-.197	-.061	-.002	.029	.084	-.153
2	P16	.541	.039	-.24	-.073	.02	.109	.156	-.232
2	P17	-.607	-.013	.368	.11	-.011	-.197	-.127	.243
2	P18	-.607	.013	.368	.11	.011	-.197	-.127	-.243
2	P19	-.541	-.039	.24	.073	-.02	.109	.156	-.232
2	P20	-.94	.035	.197	.061	.002	.029	.084	-.153
2	P21	.089	-.176	.078	.078	.005	-.494	-.206	-.089
2	P22	-.089	-.176	.078	.078	-.005	-.494	-.206	.089
2	P23	-.068	.188	.053	.044	.029	-.472	-.553	-.107
2	P24	.068	.188	.053	.044	-.029	-.472	-.553	.107
2	P25	0	0	0	0	0	.078	.792	.666
2	P26	0	0	0	0	0	-2.028	-1.637	2.12
2	P27	0	0	0	0	0	.018	.003	-.248
2	P28	0	0	0	0	0	-.018	-.356	.248
2	P29	0	0	0	0	0	-.08	.264	-.32
2	P30	0	0	0	0	0	-.07	-.363	1.098
2	P31	0	0	0	0	0	-.31	-2.432	1.211



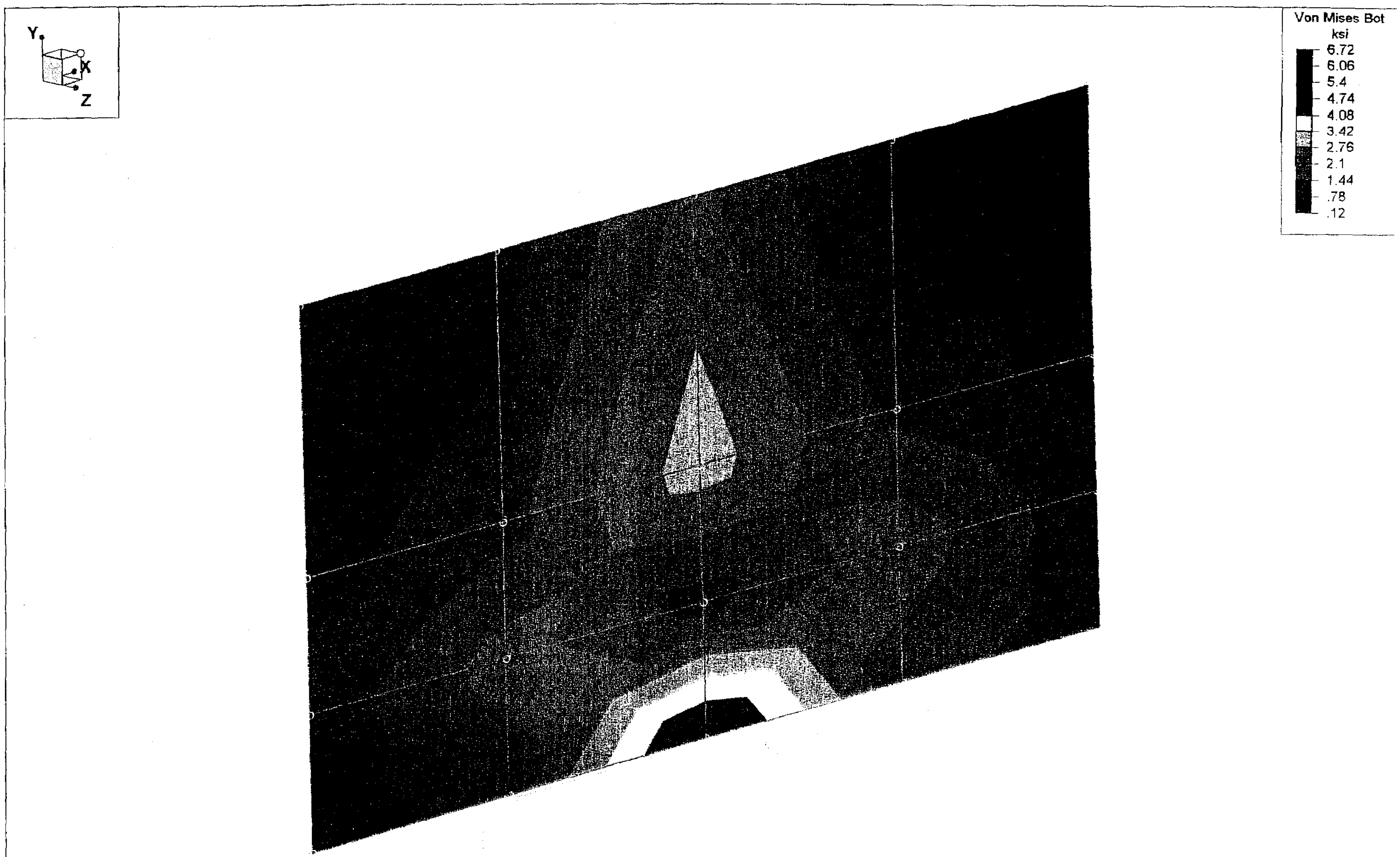
Results for LC 2, Upper Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:14 PM
		Tank lift pad .625 wall.r3d



Results for LC 2, Upper Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug Tank Wall Only	December 2, 2003
ITR		6:17 PM
		Tank lift pad .625 wall.r3d



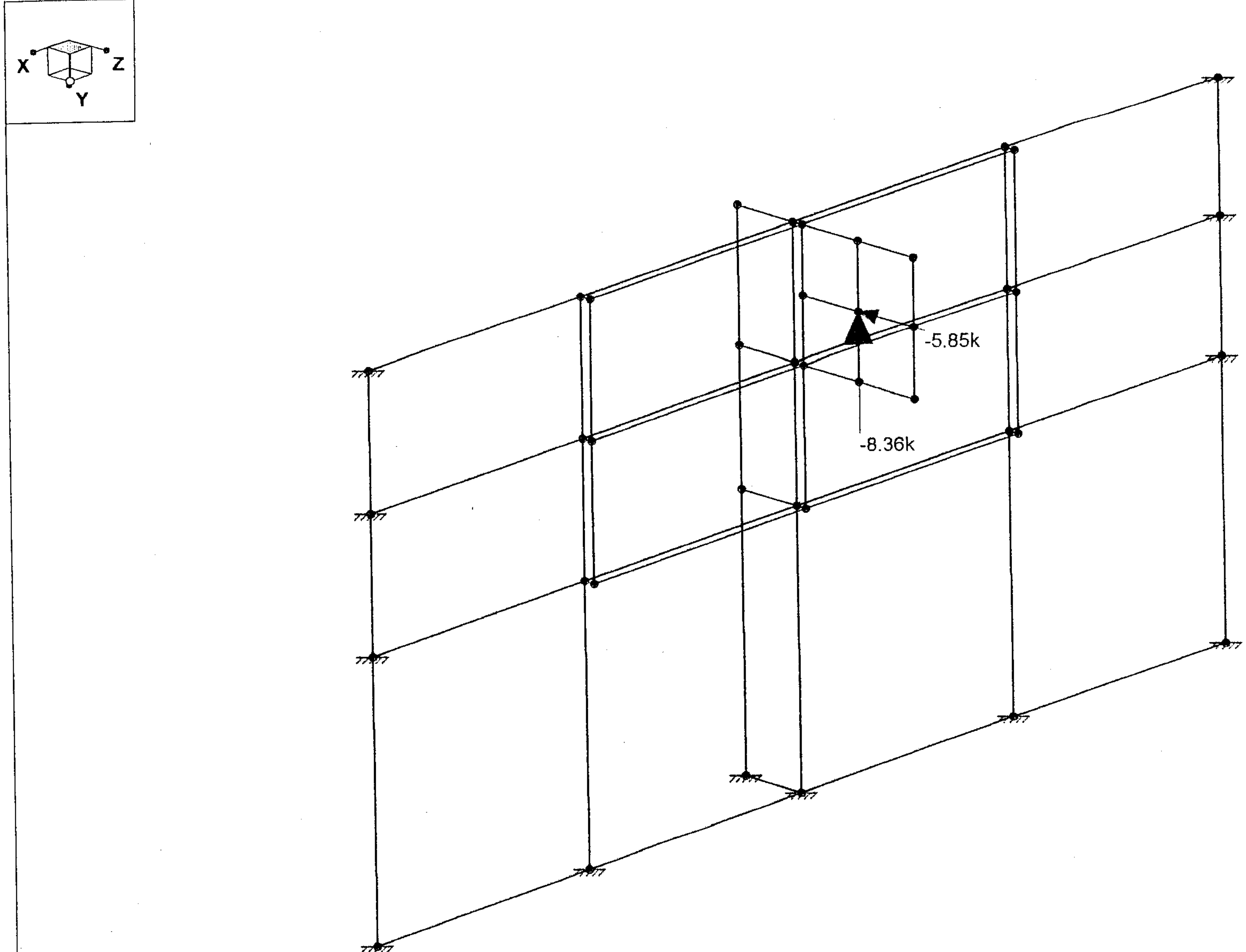
Results for LC 2, Upper Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:19 PM
		Tank lift pad .625 wall.r3d



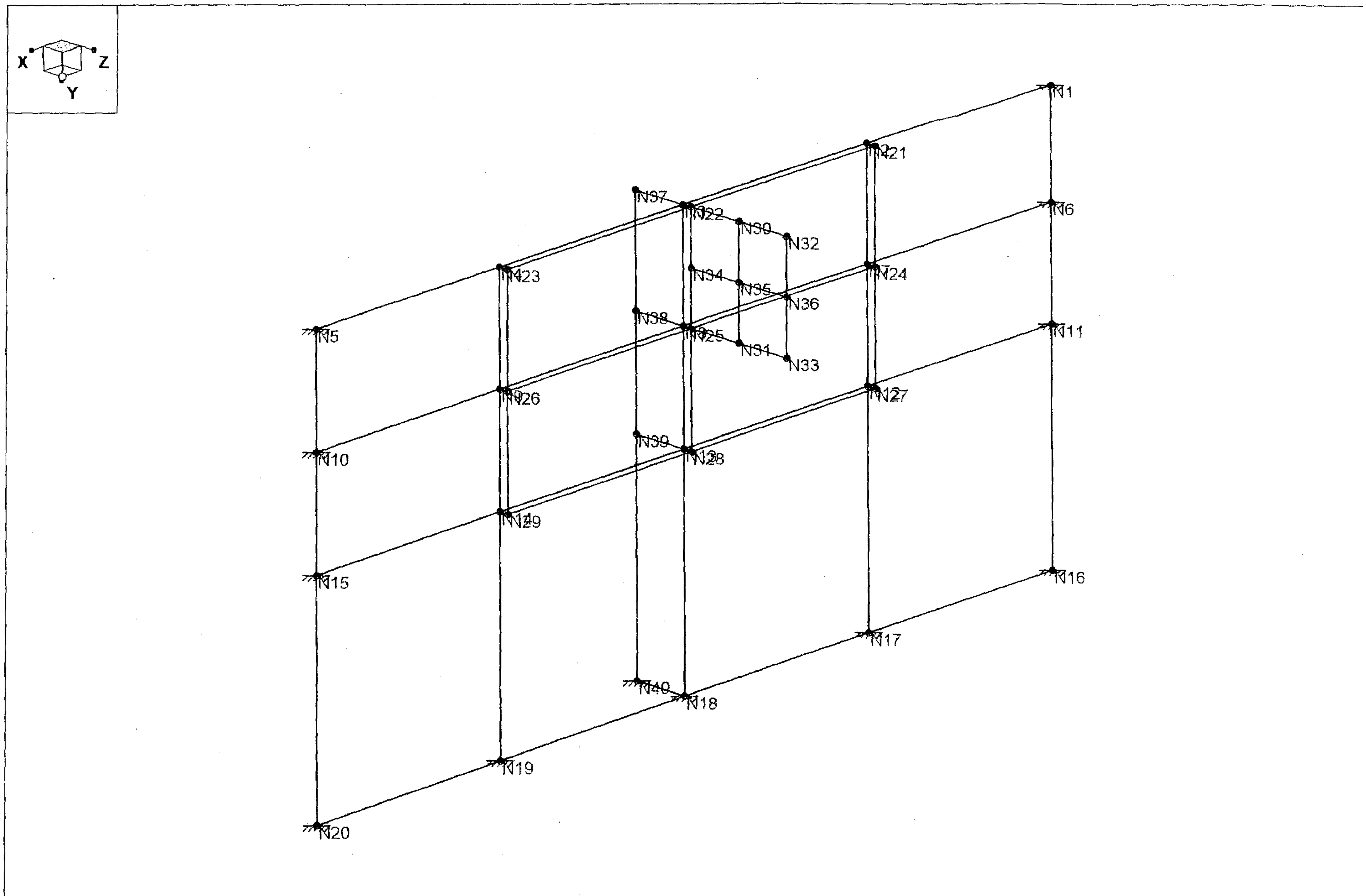
Results for LC 2, Upper Half 5/8 wall		
Intrepid Technology and Resources, ...	PM-2A Tank Lug Tank wall Only	December 2, 2003
ITR		6:11 PM
		Tank lift pad .625 wall.r3d

RISA 3D ANALYSIS

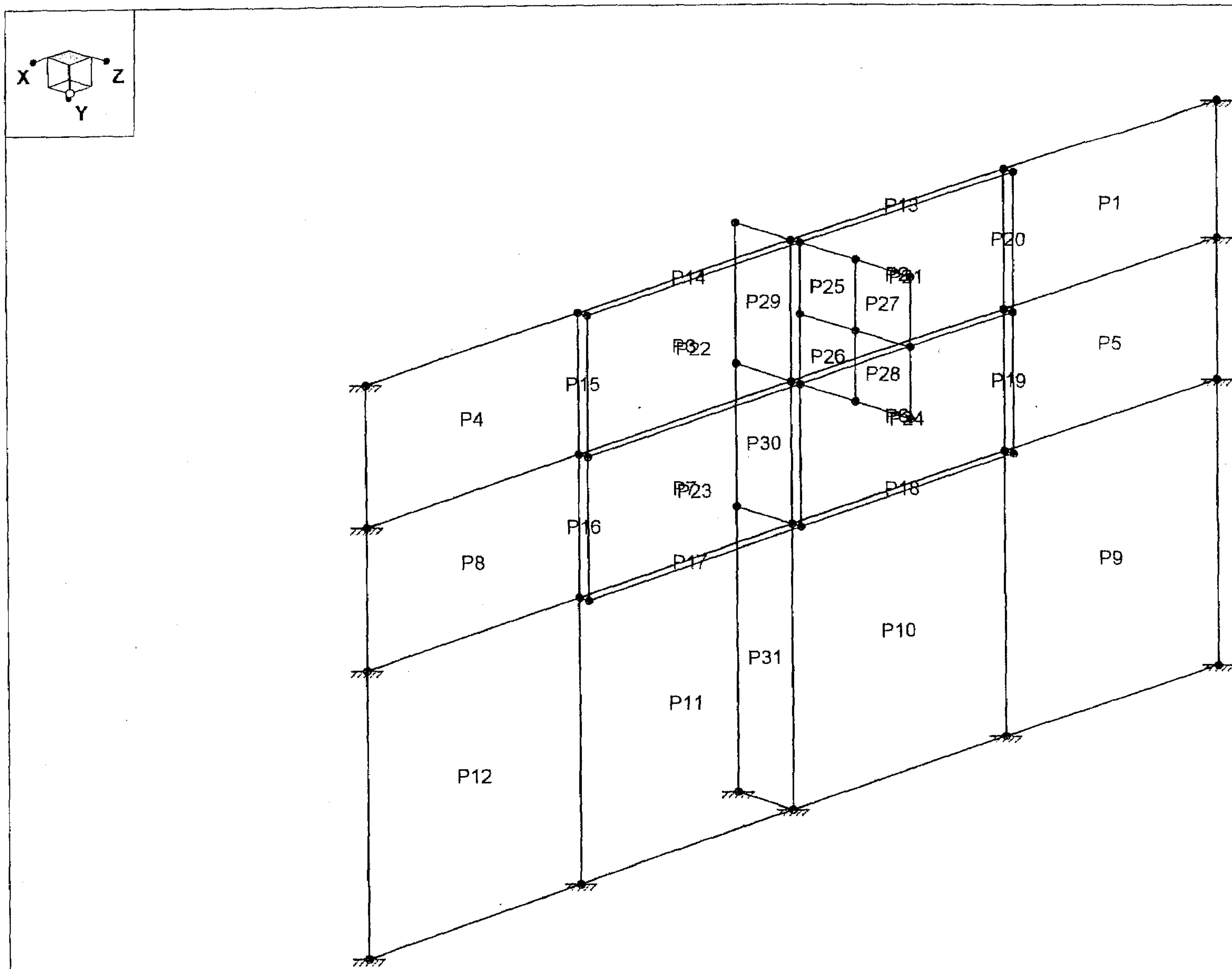
LOWER HALF TANK



Loads: LC 1, Lower Half 5/8 wall	PM-2A Tank Lug	December 2, 2003
Intrepid Technology and Resources, ...		6:32 PM
ITR		Tank lift pad .625 wall.r3d



Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:33 PM
		Tank lift pad .625 wall.r3d



Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:35 PM
		Tank lift pad .625 wall.r3d

Joint Coordinates

Joint Label	X Coordinate (in)	Y Coordinate (in)	Z Coordinate (in)	Joint Temperature (F)	Detach from Diaphragm
N1	0	0	0	0	No
N2	12	0	0	0	No
N3	24	0	0	0	No
N4	36	0	0	0	No
N5	48	0	0	0	No
N6	0	6	0	0	No
N7	12	6	0	0	No
N8	24	6	0	0	No
N9	36	6	0	0	No
N10	48	6	0	0	No
N11	0	12	0	0	No
N12	12	12	0	0	No
N13	24	12	0	0	No
N14	36	12	0	0	No
N15	48	12	0	0	No
N16	0	24	0	0	No
N17	12	24	0	0	No
N18	24	24	0	0	No
N19	36	24	0	0	No
N20	48	24	0	0	No
N21	12	0	.5	0	No
N22	24	0	.5	0	No
N23	36	0	.5	0	No
N24	12	6	.5	0	No
N25	24	6	.5	0	No
N26	36	6	.5	0	No
N27	12	12	.5	0	No
N28	24	12	.5	0	No
N29	36	12	.5	0	No
N30	24	0	3.5	0	No
N31	24	6	3.5	0	No
N32	24	0	6.5	0	No
N33	24	6	6.5	0	No
N34	24	3	.5	0	No
N35	24	3	3.5	0	No
N36	24	3	6.5	0	No
N37	24	0	-3	0	No
N38	24	6	-3	0	No
N39	24	12	-3	0	No
N40	24	24	-3	0	No

Plate/Shell Elements

Plate Label	A Joint	B Joint	C Joint	D Joint	Material Set	Thickness (in)	Stress Location 'R'	Stress Location 'S'	Inactive?
P1	N1	N6	N7	N2	STL	.625	0	0	
P2	N2	N7	N8	N3	STL	.625	0	0	
P3	N3	N8	N9	N4	STL	.625	0	0	
P4	N4	N9	N10	N5	STL	.625	0	0	
P5	N6	N11	N12	N7	STL	.625	0	0	
P6	N7	N12	N13	N8	STL	.625	0	0	
P7	N8	N13	N14	N9	STL	.625	0	0	
P8	N9	N14	N15	N10	STL	.625	0	0	
P9	N11	N16	N17	N12	STL	.625	0	0	
P10	N12	N17	N18	N13	STL	.625	0	0	
P11	N13	N18	N19	N14	STL	.625	0	0	
P12	N14	N19	N20	N15	STL	.625	0	0	
P13	N21	N2	N3	N22	STL	.625	0	0	
P14	N22	N3	N4	N23	STL	.625	0	0	
P15	N23	N4	N9	N26	STL	.625	0	0	
P16	N26	N9	N14	N29	STL	.625	0	0	
P17	N28	N13	N14	N29	STL	.625	0	0	
P18	N27	N12	N13	N28	STL	.625	0	0	
P19	N24	N7	N12	N27	STL	.625	0	0	
P20	N21	N2	N7	N24	STL	.625	0	0	
P21	N21	N22	N25	N24	STL	.625	0	0	
P22	N22	N23	N26	N25	STL	.625	0	0	
P23	N25	N26	N29	N28	STL	.625	0	0	
P24	N24	N25	N28	N27	STL	.625	0	0	
P25	N30	N22	N34	N35	STL	.75	0	0	
P26	N35	N34	N25	N31	STL	.75	0	0	
P27	N32	N30	N35	N36	STL	.75	0	0	
P28	N36	N35	N31	N33	STL	.75	0	0	
P29	N3	N37	N38	N8	STL	1	0	0	
P30	N8	N38	N39	N13	STL	1	0	0	
P31	N13	N39	N40	N18	STL	1	0	0	

Joint Loads/Enforced Displacements, Category : None, BLC 1 : Lower Half 5/8 wall

Joint Label	[L]oad,[M]ass,or [D]isplacement	Direction	Magnitude (k, k-in, in, rad, k*s^2/in)
N35	L	Y	-8.36
N35	L	Z	-5.85

Reactions, By Combination

LC	Joint Label	X Force (k)	Y Force (k)	Z Force (k)	X Moment (k-in)	Y Moment (k-in)	Z Moment (k-in)
1	N1	2.345	1.038	.838	.103	-5.234	0
1	N6	2.139	-.937	.659	-.284	-4.478	0
1	N11	-.449	-.349	.008	-.038	-.365	0
1	N16	-1.118	1.38	-.064	.022	-.012	0
1	N17	-1.41	5.033	-.044	.279	-.256	0
1	N18	0	25.219	-2.275	-.469	0	0
1	N40	0	-29.187	5.332	0	0	0
1	N19	1.41	5.033	-.044	.279	.256	0
1	N20	1.118	1.38	-.064	.022	.012	0
1	N15	.449	-.349	.008	-.038	.365	0
1	N10	-2.139	-.937	.659	-.284	4.478	0
1	N5	-2.345	1.038	.838	.103	5.234	0
1	Totals:	0	8.36	5.85			
1	COG (in):	X: 24	Y: 3	Z: 3.5			

Plate/Shell Principal Stresses, By Combination

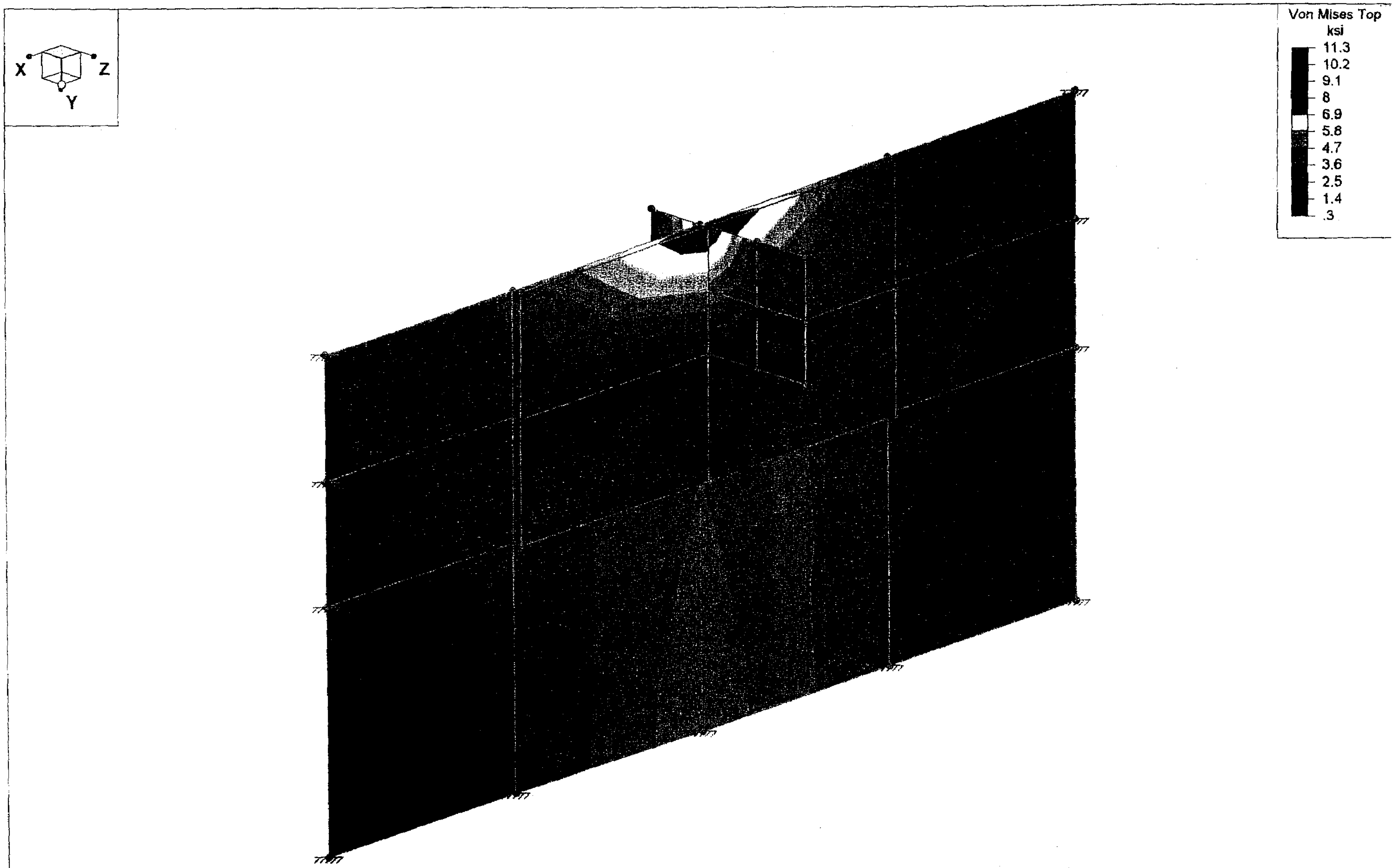
LC	Plate Label	Surface [T]op / [B]ottom	Sigma1 (ksi)	Sigma2 (ksi)	Tau Max (ksi)	Angle (radians)	Von Mises (ksi)
1	P1	T	1.336	-.039	.687	-.609	1.356
		B	-.751	-3	1.124	-.312	2.704
1	P2	T	.349	-1.171	.76	.534	1.38
		B	2.693	.117	1.288	.22	2.637
1	P3	T	.349	-1.171	.76	-.534	1.38
		B	2.693	.117	1.288	-.22	2.637
1	P4	T	1.336	-.039	.687	.609	1.356
		B	-.751	-3	1.124	.312	2.704
1	P5	T	1.276	.172	.552	-.644	1.2
		B	-.312	-1.54	.614	-.498	1.411
1	P6	T	1.313	-.536	.924	.309	1.648
		B	1.344	.007	.669	.397	1.34
1	P7	T	1.313	-.536	.924	-.309	1.648
		B	1.344	.007	.669	-.397	1.34
1	P8	T	1.276	.172	.552	.644	1.2
		B	-.312	-1.54	.614	.498	1.411
1	P9	T	1.059	.301	.379	.655	.945
		B	-.004	-.238	.117	-.295	.237
1	P10	T	1.857	.12	.869	.199	1.8
		B	.3	.073	.113	.494	.271
1	P11	T	1.857	.12	.869	-.199	1.8
		B	.3	.073	.113	-.494	.271
1	P12	T	1.059	.301	.379	-.655	.945
		B	-.004	-.238	.117	.295	.237
1	P13	T	3.65	-2.333	2.991	-.714	5.223
		B	2.437	-4.826	3.631	.691	6.402
1	P14	T	3.65	-2.333	2.991	.714	5.223
		B	2.437	-4.826	3.631	-.691	6.402
1	P15	T	1.882	.884	.499	.288	1.631
		B	-.346	-2.188	.921	.349	2.037
1	P16	T	1.086	0	.543	-.675	1.086
		B	1.023	-1.576	1.299	.573	2.268
1	P17	T	-.091	-1.004	.457	.626	.962
		B	.985	-.726	.856	.512	1.488
1	P18	T	-.091	-1.004	.457	-.626	.962
		B	.985	-.726	.856	-.512	1.488
1	P19	T	1.023	-1.576	1.299	.573	2.268
		B	1.086	0	.543	-.675	1.086
1	P20	T	-.346	-2.188	.921	.349	2.037
		B	1.882	.884	.499	.288	1.631
1	P21	T	.611	.427	.092	-.069	.543
		B	1.11	-3.084	2.097	-.32	3.765
1	P22	T	.611	.427	.092	.069	.543
		B	1.11	-3.084	2.097	.32	3.765
1	P23	T	.255	-.325	.29	.42	.504
		B	1.527	-2.079	1.803	.343	3.135
1	P24	T	.255	-.325	.29	-.42	.504
		B	1.527	-2.079	1.803	-.343	3.135
1	P25	T	.783	-4.82	2.802	.662	5.256
		B	.783	-4.82	2.802	.662	5.256
1	P26	T	2.349	-.341	1.345	.419	2.537
		B	2.349	-.341	1.345	.419	2.537
1	P27	T	.216	-.836	.526	-.497	.963
		B	.216	-.836	.526	-.497	.963
1	P28	T	.399	-.495	.447	.705	.776
		B	.399	-.495	.447	.705	.776

Plate/Shell Principal Stresses, By Combination, (continued)

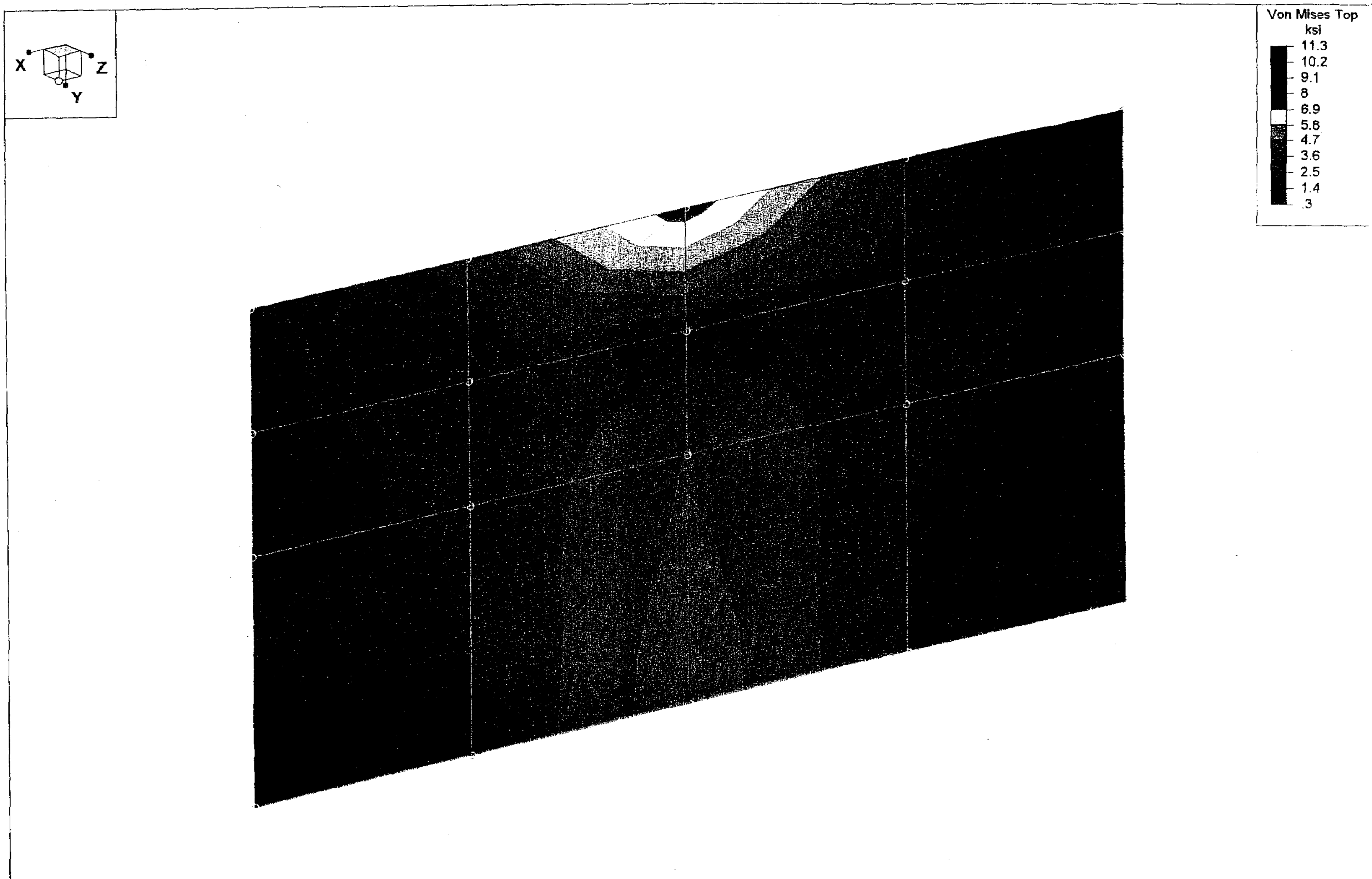
LC	Plate Label	Surface [T]op / [B]ottom	Sigma1 (ksi)	Sigma2 (ksi)	Tau Max (ksi)	Angle (radians)	Von Mises (ksi)
1	P29	T	.501	-2.503	1.502	.56	2.787
		B	.501	-2.503	1.502	.56	2.787
1	P30	T	.553	-4.298	2.426	.305	4.6
		B	.553	-4.298	2.426	.305	4.6
1	P31	T	-.024	-4.021	1.999	.28	4.009
		B	-.024	-4.021	1.999	.28	4.009

Plate/Shell Forces, By Combination

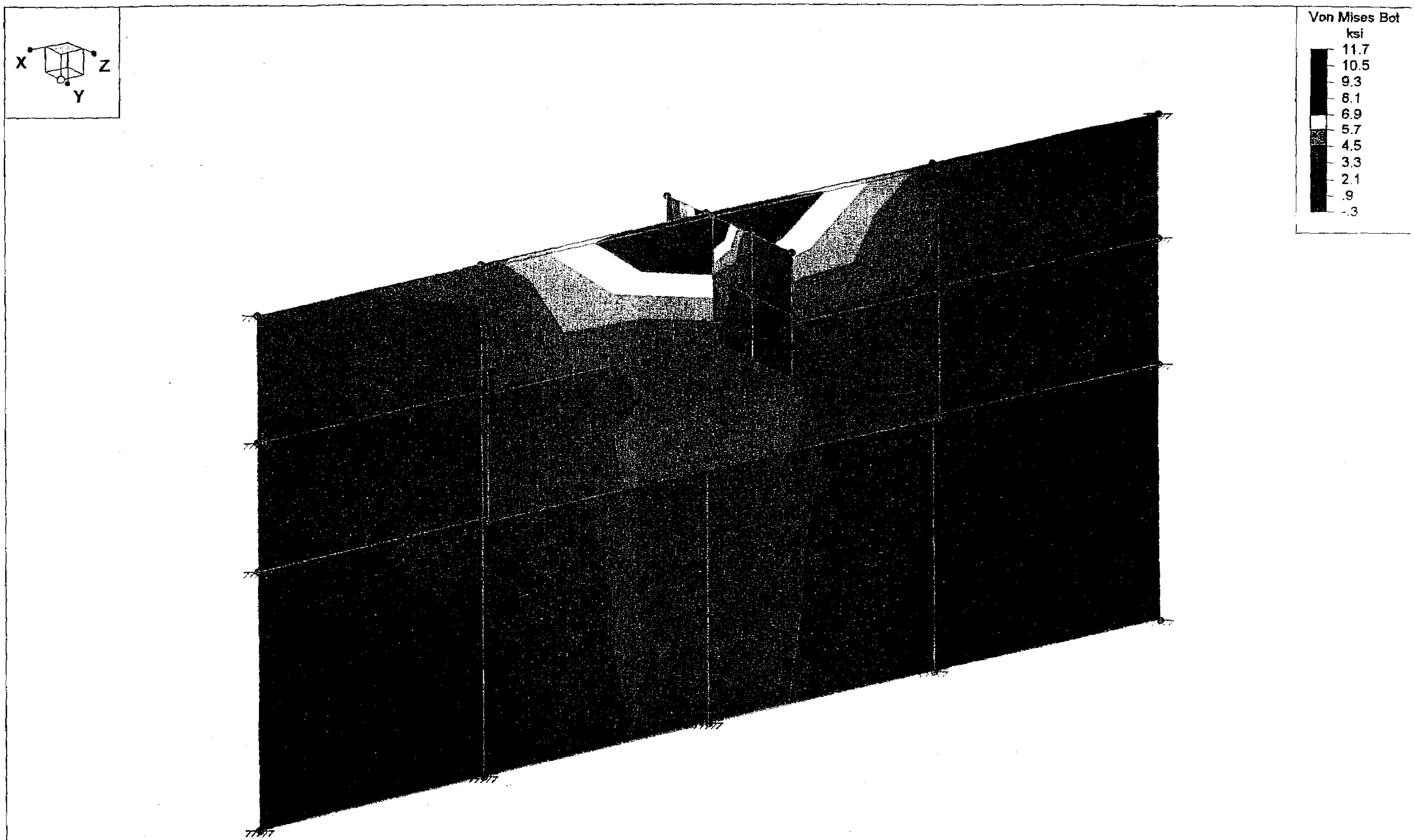
LC	Plate Label	Qx (k/in)	Qy (k/in)	Mx (k-in/in)	My (k-in/in)	Mxy (k-in/in)	Fx (k/in)	Fy (k/in)	Fxy (k/in)
1	P1	.001	.228	.045	.12	.042	-.173	-.594	-.004
1	P2	.001	-.077	-.009	-.109	.04	.061	.56	.037
1	P3	.001	.077	-.009	-.109	-.04	.061	.56	-.037
1	P4	.001	-.228	.045	.12	-.042	-.173	-.594	.004
1	P5	-.002	.027	.038	.07	.034	-.007	-.119	.004
1	P6	.019	0	.03	-.049	.033	.421	.243	.018
1	P7	.019	0	.03	-.049	-.033	.421	.243	-.018
1	P8	-.002	-.027	.038	.07	-.034	-.007	-.119	-.004
1	P9	-.009	-.007	.026	.026	.014	.236	.114	.094
1	P10	-.006	.013	.054	-.002	.014	.598	.136	.076
1	P11	-.006	-.013	.054	-.002	-.014	.598	.136	-.076
1	P12	-.009	.007	.026	.026	-.014	.236	.114	-.094
1	P13	-.306	.007	.096	.024	.02	-.247	-.088	-2.04
1	P14	-.306	-.007	.096	.024	-.02	-.247	-.088	2.04
1	P15	1.707	.004	.123	.05	.028	-.053	.126	-.1
1	P16	.364	.012	.048	.005	.021	-.047	.214	-.535
1	P17	.337	-.007	-.032	-.012	-.01	.053	-.314	.364
1	P18	.337	.007	-.032	-.012	.01	.053	-.314	-.364
1	P19	-.364	-.012	-.048	-.005	-.021	-.047	.214	-.535
1	P20	-1.707	-.004	-.123	-.05	-.028	-.053	.126	-.1
1	P21	.078	.059	.101	-.003	-.04	-.7	.408	.395
1	P22	-.078	.059	.101	-.003	.04	-.7	.408	-.395
1	P23	-.004	-.049	.047	-.031	.03	-.594	.399	-.424
1	P24	.004	-.049	.047	-.031	-.03	-.594	.399	.424
1	P25	0	0	0	0	0	-2.028	-1	-2.037
1	P26	0	0	0	0	0	.078	1.428	-.749
1	P27	0	0	0	0	0	-.018	-.448	-.331
1	P28	0	0	0	0	0	.018	-.089	.331
1	P29	0	0	0	0	0	-.346	-1.656	1.351
1	P30	0	0	0	0	0	.116	-3.861	1.389
1	P31	0	0	0	0	0	-.329	-3.716	1.062



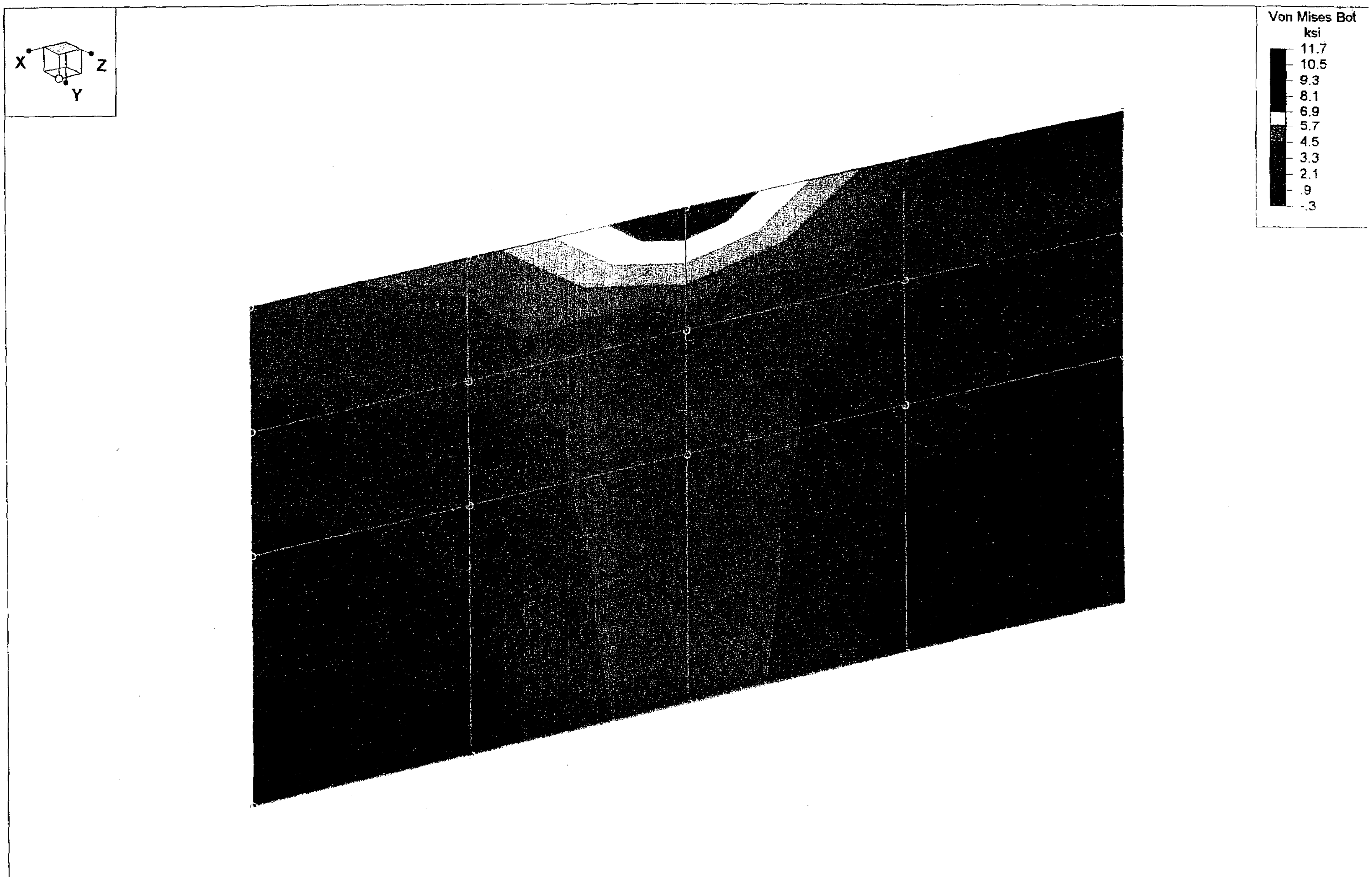
Results for LC 1, Lower Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:40 PM
		Tank lift pad .625 wall.r3d



Results for LC 1, Lower Half 5/8 wall		
Intrepid Technology and Resources, ...	PM-2A Tank Lug Tank Wall Only	December 2, 2003
ITR		6:41 PM
		Tank lift pad .625 wall.r3d



Results for LC 1, Lower Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug	December 2, 2003
ITR		6:45 PM
		Tank lift pad .625 wall.r3d

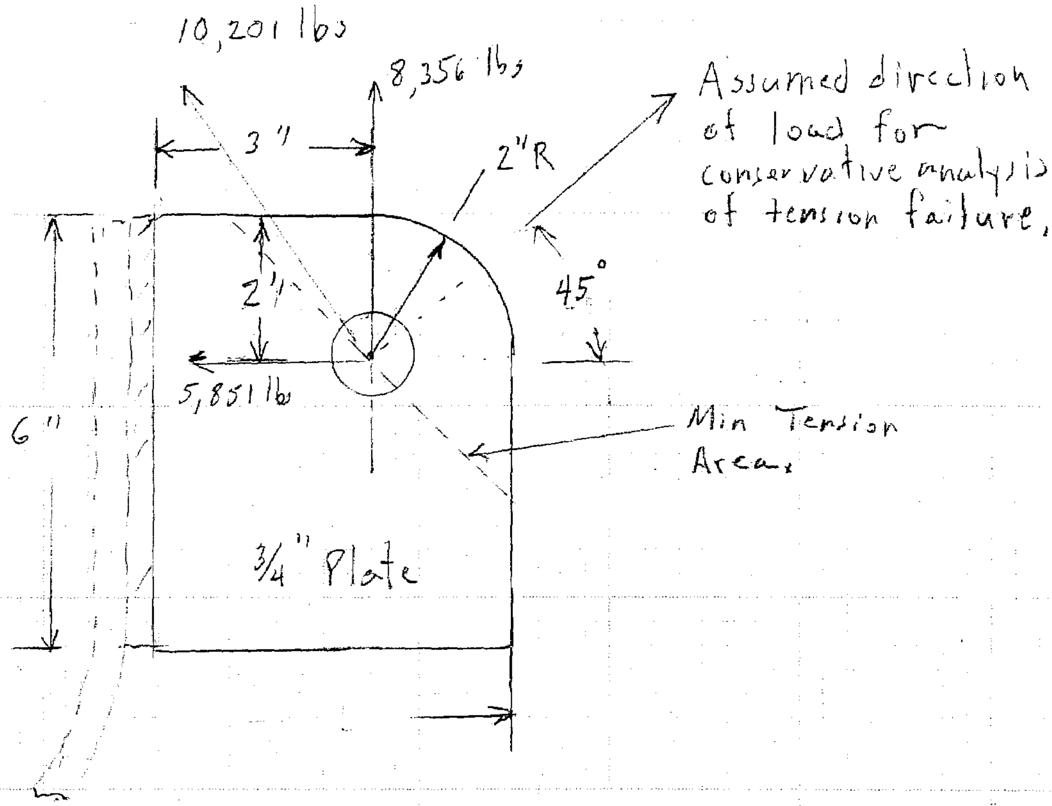


Results for LC 1, Lower Half 5/8 wall		
Intrepid Technology and Resources, ..	PM-2A Tank Lug Tank Wall Only	December 2, 2003
ITR		6:43 PM
		Tank lift pad .625 wall.r3d

LIFTING LUG ANALYSIS

INTREPID
Engineering Services, Inc.
A New Type of Engineering Company
501 West Broadway, Suite 200 Idaho Falls, ID 83402
(208) 529-5337

JOB PM-2A Half Tank Lifting Lug
SHEET NO. 1 OF
CALCULATED BY Lowell DATE 12/3/04
CHECKED BY DATE
SCALE



To simplify the analysis we use the minimum tension area and assume the cable tension load is normal to the area

Tension Area = (plate thickness)(net tension length)

$$= (3/4)(2 \times 2/\cos 45^\circ - 1\tfrac{3}{16}) = 3.35 \text{ in}^2$$

$$f_a = P/A = 10{,}201/3.352 = 3{,}043 \text{ psi or } 3.04 \text{ kips}$$

Factor of Safety based on yield strength

$$S.F = 36/3.04 = 11.84$$

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JOB PM-2A Half Tank Lifting Lugs
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Bearing Loads on Lugs

Lug will be fabricated from 3/4" steel plate.
Material A 36 $F_y = 36$ ksi $F_u = 58$ ksi (Minimum for A 36)
For 1" ~~shackle~~ Shackle Bolt 1 1/8" diam
Hole 1 1/8 + 1/16 = 1 3/16" hole.

AISC Manual of Steel Construction Table 1-E
Page 4-6 Ninth Edition
Minimum edge distance - Center of hole to edge
greater than 1.5 d. Where d is diameter of pin
Minimum edge distance = (1.5)(1.125) = 1.69 inches
(See Notes of Table 1-E)

Edge distance 2" > 1.69 inches required and is adequate.

From Table 1-E for $F_u = 58$ ksi (Lowest value for all materials) and lug thickness of 3/4" and a shackle pin diameter of 1" allowable load is 52.2 kips
(Table does not have value for 1 1/8" pin but use of value for 1" pin is conservative)

Tension Load = 10,201 lbs < 52.2 lbs allowable load and lug is adequate.

1,275

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Section J3.9 of the Specification in the Manual of Steel Construction also requires Minimum Edge Distance be greater than value from Table J3.5.

For nominal bolt diameter of 1 1/8" inch the minimum edge distance from center of hole to edge is 1 1/2 inches

$2 > 1\frac{1}{2}$ inches. Edge distance is adequate

Also edge distance shall not be less than

$$L_e \geq 2P/F_u t = (2)(10.20)/(58)(0.75) = 0.469 \text{ inches}$$

$2 > 0.469$ Edge distance is adequate.

Also Section J3.7 requires for single bolt in line of force

$$f_{bearing} < F_p$$

$$f_{bearing} = \frac{P}{dt} = 10.20/(1.125)(0.75) = 12.09 \text{ ksi}$$

$$F_p = L_e F_u / 2d = (2.0)(58)/(2)(1.125) = 51.6 \text{ ksi}$$

Where $L_e = 2$ is the distance from the free edge to center of hole.

Also F_p cannot exceed

$$1.2 F_u = (1.2)(58) = 69.6$$

$51.6 < 69.6$ therefore the limit is 51.6 ksi

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Pin bearing stress $12.09 < 51.6$

Factor of safety $= \frac{51.6}{12.09} = 4.27$

Bearing of 1 1/8" diam bolt of 1 inch shackle is acceptable

Lug with 3/4" plate and 1 3/16" hole and 2" radius to edge of plate is adequate with large margin.

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JOB PM-2A Half Tank Lifting Lug
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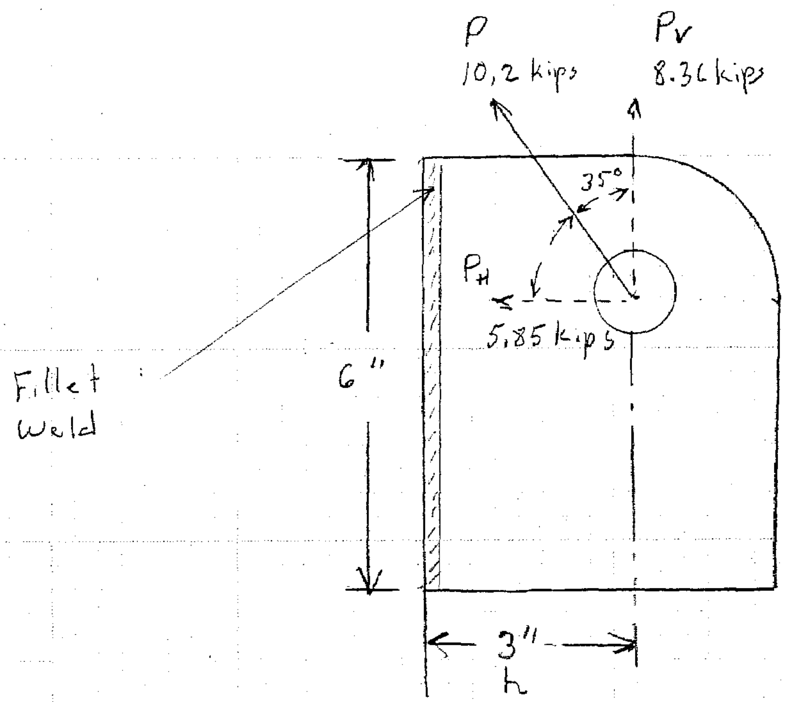


Tension in the cable $P = 10.20$ kips

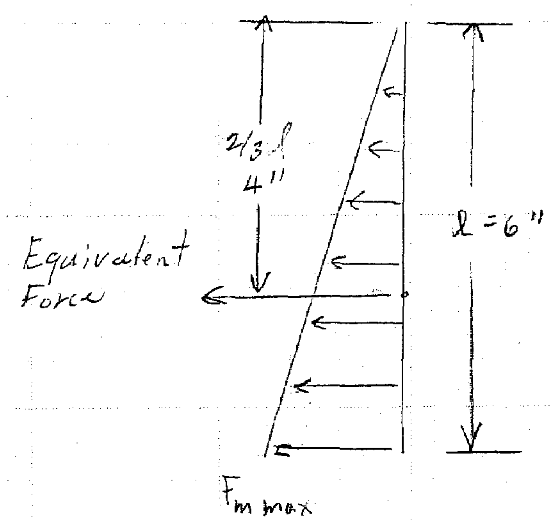
Horizontal component $P_H = (10.20)(\sin 35°) = 5.85$ kips

Vertical component $P_V = (0.20)(\cos 35°) = 8.36$ kips.

Vertical Component produces moment at base of lug. Moment $= P_V h = (8.36)(3) = 25.08$ kip-in

There is a fillet on each side of the lug so the moment on one fillet is $M = 25.08/2 = 12.54$ kip inches.

The stress resisting the moment is approximated as a linear distribution.



Where F_m units are kips per inch of weld length.

The moment resisted by the distributed stress

$$M = (\text{Total Force})(\text{Distance to center of force})$$

$$= \left(\tfrac{1}{2} F_{m\,max}\, l\right)\left(\tfrac{2}{3} l\right) = \frac{F_{m\,max}\, l^2}{3}$$

Set equal to the moment from sheet 5 and solve for $F_{m\,max}$

$$\frac{F_{m\,max}\, l^2}{2} = \frac{F_{m\,max}\, 6^2}{3} = 12.54 \text{ kip inches}$$

$$F_{m\,max} = \frac{(3)(12.54)}{6^2} = 1.05 \text{ kips per inch of meld.}$$

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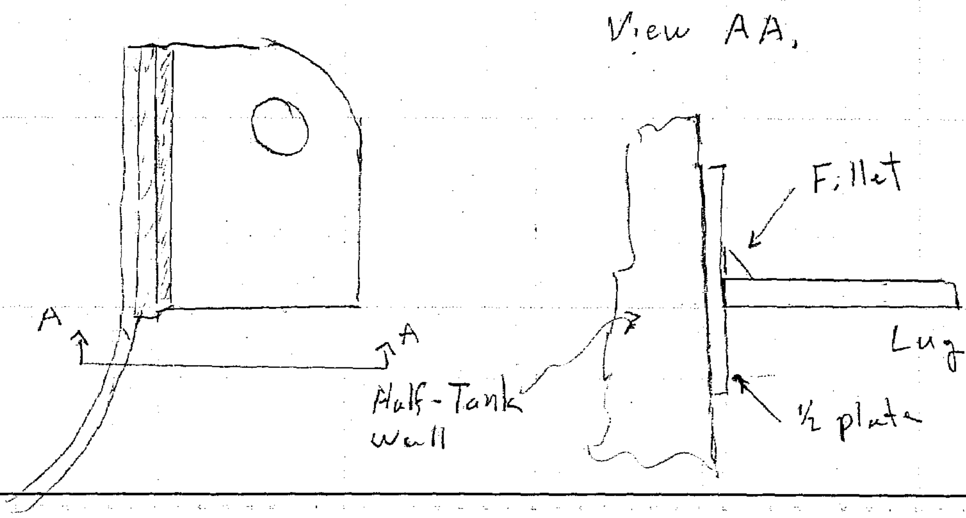
The horizontal component of the force will produce compression on the joint. The compression will be taken by the lug material and will not load the fillet weld.

The vertical component of the force also produce shear on the weld parallel to the axis of the weld. The shear load is taken as uniform over the length of the weld. The shear per unit length of fillet on one side

$V = \frac{1}{2} P_v / l = (\frac{1}{2})(8.36)/6 = 0.697$ kips per inch of weld.

To determine maximum shear stress at the throat of the weld, the component stresses are calculated.

The moment from the vertical force component produces tension force on the fillet which results in tension and shear at the fillet throat



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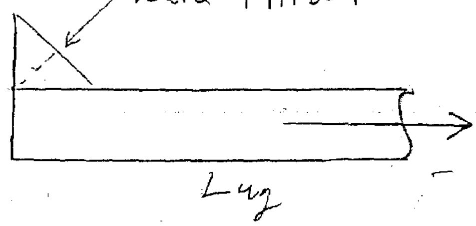
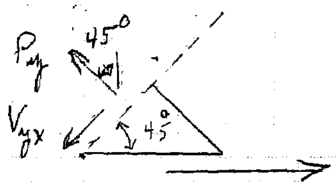


Forces on weld throat at location of max stress.



Σ Forces $\rightarrow$ $\quad 1.05 = P_y \cos 45 + V_{yx} \cos 45 \quad (1)$

Σ Forces $\uparrow$ $\quad 0 = P_y \cos 45 - V_{yx} \cos 45 \quad (2)$

$$2 P_y \cos 45 = 1.05$$

$P_y = 0.742$ kips per inch

From eq.(2) $\quad V_{yx} = P_y = 0.742$ kips per inch.

From Table J2.4 of the Speification in the Manual of Steel Construction, the minimum weld size for 3/4 inch plate is 1/4 inch. To obtain a factor of safety of at least 3 a larger weld size of 1/2 inch is used

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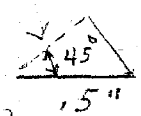
The area of the throat for 1 inch of length is

$.5\cos 45$



$A_t = (0.5\cos 45)(1 \text{ inch of length}) = 0.354 \text{ in}^2$

$\sigma_y = P_y/A_t = 0.742/0.354 = 2.096$

$\tau_{yx} = V_{yx}/A_t = 0.742/0.354 = 2.096$

$\tau_{yz} = V/A_t = 0.697/0.354 = 1.969$, V from page 7

The component principal stresses are determined from the solution of the cubic equation. See attached page from ASTM Handbook Volume 11 Failure Analysis and Prevention

The coefficients for the cubic equation

$I_1 = \sigma_x + \sigma_y + \sigma_x = 0 + 2.096 + 0 = 2.096$

$I_2 = \sigma_x\sigma_z + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2$

$= 0 + 0 + 0 - 2.096^2 - 0 - 1.969^2 = -8.270$

$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{xz}\tau_{yz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2$

$= 0 + 0 - 0 - 0 - 0 = 0$

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Cubic Equation

$$\sigma^3 - I_1\sigma^2 + I_2\sigma - I_3 = 0$$

$$\sigma^3 - 2.096\sigma^2 - 8.270 - 0 = 0$$

Solution for cubic equation from

www.1728.com/cubic.htm (Sheet Attached)

$\sigma_1 = 4.109$ ksi

$\sigma_2 = -2.013$ ksi

$\sigma_3 = 0$

$$\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} = \frac{4.109 + 2013}{2} = 3.06 \text{ ksi}.$$

Allowable Stress from Table J2.5 of the Specification in the AISC Manual of Steel Construction

$$\tau_{max\ allowable} = 0.3 F_u$$

For weld filler metal $F_u = 70$ksi

$$\tau_{max\ allowable} = (0.3)(70) = 21 \text{ ksi}.$$

$\tau_{max} = 3.06 < 21$ ksi allowable and 1/2" filled weld is adequate.

Factor of Safety $21/3.06 = 6.86$

8. COMBINED STRESS

Under certain circumstances of loading a body is subjected to a combination of tensile, compressive, and/or shear stresses. For example, a shaft which is simultaneously bent and twisted is subjected to combined stresses, namely, longitudinal tension and compression and torsional shear. For the purposes of analysis it is convenient to reduce such systems of combined stresses to a basic system of stress coordinates known as principal stresses. These stresses act on axes which differ in general from the axes along which the applied stresses are acting and represent the maximum and minimum values of the normal stresses for the particular point considered.

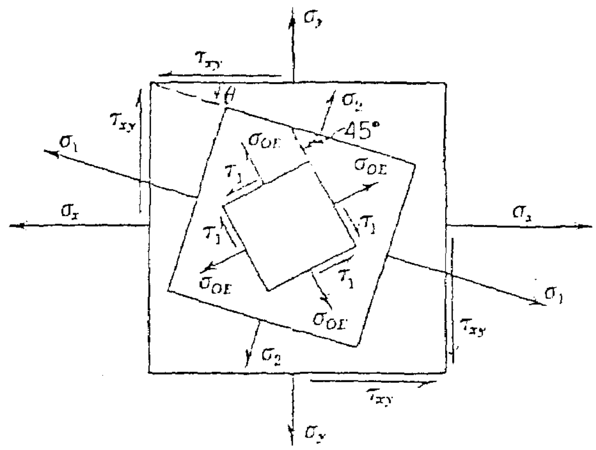

FIG. 1. Diagram showing relative orientation of stresses. (Reproduced with modification by permission from *Mechanical Properties of Materials and Design*, by Joseph Marin, McGraw-Hill Book Co.)

Determination of Principal Stresses. The expressions for the principal stresses in terms of the stresses along the x and y axes are

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \qquad (1)$$

$$\sigma_2 = \frac{\sigma_x + \sigma_y}{2} - \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \qquad (2)$$

$$\tau_1 = \pm\sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \qquad (3)$$

where σ_1, σ_2, and τ_1 are the principal stress components and σ_x, σ_y, and τ_{xy} the calculated stress components, all of which are determined at any particular point (Fig. 1).

Graphical Method of Principal Stress Determination—Mohr's Circle. Let the axes x and y be chosen to represent the directions of the applied normal and shearing stresses, respectively (Fig. 2). Lay off to suitable scale distances $OA = \sigma_y$, $OB = \sigma_x$, and $BC = AD = \tau_{xy}$. With point E as a center construct the circle DFC. Then OF and OG are the principal stresses σ_1 and σ_2 respectively, and EC the maximum shear stress τ_1. The inverse also holds; that is, given the principal stresses, σ_x and σ_y can be determined on any plane passing through the point.

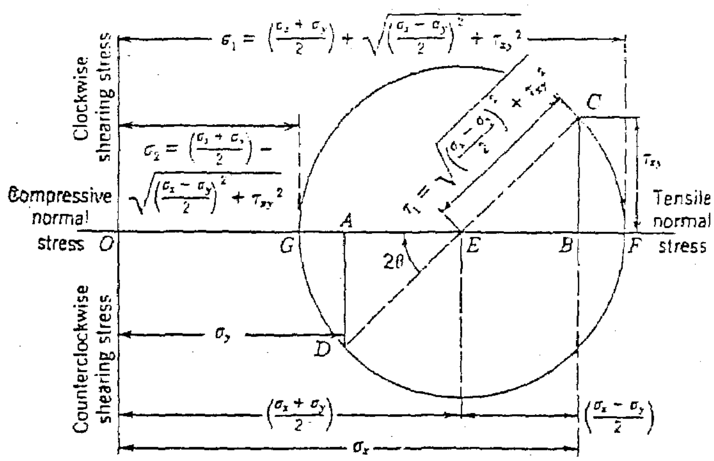

FIG. 2. Mohr's circle used for the determination of the principal stresses. (Reproduced with modification by permission from Joseph Marin, *op. cit.*)

Stress-strain Relations. The linear relation between components of stress and strain is known as *Hooke's law*. This relation for the two-dimensional case can be expressed as

$$\epsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_y) \qquad (4)$$

$$\epsilon_y = \frac{1}{E}(\sigma_y - \nu\sigma_x) \qquad (5)$$

$$\gamma_{xy} = \frac{1}{G}\tau_{xy} \qquad (6)$$

where σ_x, σ_y, and τ_{xy} are the stress components of a particular point, ν = Poisson's ratio, E = modulus of elasticity, G = modulus of rigidity, and ϵ_x, ϵ_y, and γ_{xy} = strain components.

It was noted that Eq 15 is the equation of a circle with axes σ and τ and centered on the σ axis with:

$$\text{center} = \left(\frac{\sigma_x + \sigma_y}{2}\right) \quad \text{(Eq 16)}$$

and radius, R, given by:

$$R^2 = \left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{xy}^2 \quad \text{(Eq 17)}$$

The result is that stress transformations can be performed by using the geometric principles of a circle. For example, if stresses are known at a point, they are plotted on a figure that has horizontal axis σ and vertical axis τ so that (σ_x, τ_{xy}) is the coordinate point at horizontal position σ_x and vertical position τ_{xy} and so that (σ_y, τ_{xy}) is the coordinate that corresponds to σ_y and τ_{xy}. Since the center of the circle is on the σ axis, this can be easily found by Eq 16. The radius of the circle is given by Eq 17. From this, the entire circle can be drawn. This is illustrated by the schematic Mohr's circle in Fig. 5.

Then for a rotation of axes by θ in the stress element, the position on the Mohr's circle must go through a rotation of 2θ in the same direction but around the circumference of the circle. Every point on the circle corresponds to a possible stress pair. Note that a rotation of 180° of the circle corresponds to a rotation of the stress element by 90° so that σ_x is transformed to σ_y as shown in Fig. 5.

Principal Stresses. The purpose of a stress transformation is mainly to find the stresses that can be used in a failure criterion. These would be either the largest magnitude stresses in any direction or the magnitude of stresses on a weak plane. For the former, the extreme stresses can be found by taking Eq 11 and applying the calculus principle $d\sigma_{x'}/d\theta = 0$. That is, principal stresses are normal (perpendicular) stresses on planes for which the shear stresses are zero. The values of principal stresses are given by:

$$\sigma_1, \sigma_2 = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad \text{(Eq 18)}$$

where the positive radical gives a maximum stress labeled σ_1 and the negative radical a minimum stress σ_2. Notice that the positions of the extreme stresses are the points on the Mohr's circle where the circle crosses the σ axis (horizontal axis) (Fig. 5).

The right side of the circle corresponds to a maximum normal stress and the left side to a minimum stress. These stresses as called principal stresses and are often labeled σ_1 and σ_2. Notice that the extremal stress given by Eq 18 is equivalent to taking the center $\pm$ the radius of the Mohr's circle. In this way the extreme values of stresses can be easily found by simply using the Mohr's circle.

The maximum shear stress, τ_{max}, can also be found by taking $\tau_{x'y'}$ from Eq 12 and using the calculus principal $d\tau_{x'y'}/d\theta = 0$. This results in:

$$\tau_{max} = \pm\sqrt{\left(\frac{\sigma_x + \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad \text{(Eq 19)}$$

The value of τ_{max} is the radius of the Mohr's circle, and the corresponding points on the Mohr's circle are at the top and bottom of the circle as shown in Fig. 5. The maximum shear stress could also be written as:

$$\tau_{max} = \frac{\sigma_1 - \sigma_2}{2} \quad \text{(Eq 20)}$$

Note that the maximum normal stresses are defined at a position where the shear stresses are zero. A plane with zero shear stress is defined as a principal stress plane, that is, a plane having only normal stresses. This can be extended to three dimensions. Given a symmetric stress tensor as defined previously, a transformation is desired to a plane that results in the stress tensor having only normal stress components; all shear components are zero. This would be given by:

$$\begin{pmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{pmatrix}$$

The transformation results in a cubic equation in σ given by:

$$\sigma^3 - I_1\sigma^2 + I_2\sigma - I_3 = 0 \quad \text{(Eq 21)}$$

where

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$
$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2$$
$$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{xz}\tau_{yz} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2 \quad \text{(Eq 22)}$$

The values of the coefficients, I_1, I_2, and I_3 are called the stress invariants and are independent of the coordinate system used to describe the stress state. However, here they are used to solve the stress cubic given in Eq 21 so that three principal stresses result: σ_1, σ_2, and σ_3. In three dimensions, the maximum shear stresses can be found in the same way to the 2D stresses, that is as one-half the difference of any two principal stresses.

If stresses σ_1, σ_2, and σ_3 are ordered from maximum to minimum, then the absolute maximum shear stress in three dimensions is:

$$\tau_{max(abs)} = \frac{\sigma_1 - \sigma_3}{2} \quad \text{(Eq 23)}$$

The transformation of stress in three dimensions can be made with equations like Eq 14. For this transformation, a circle like the Mohr's circle

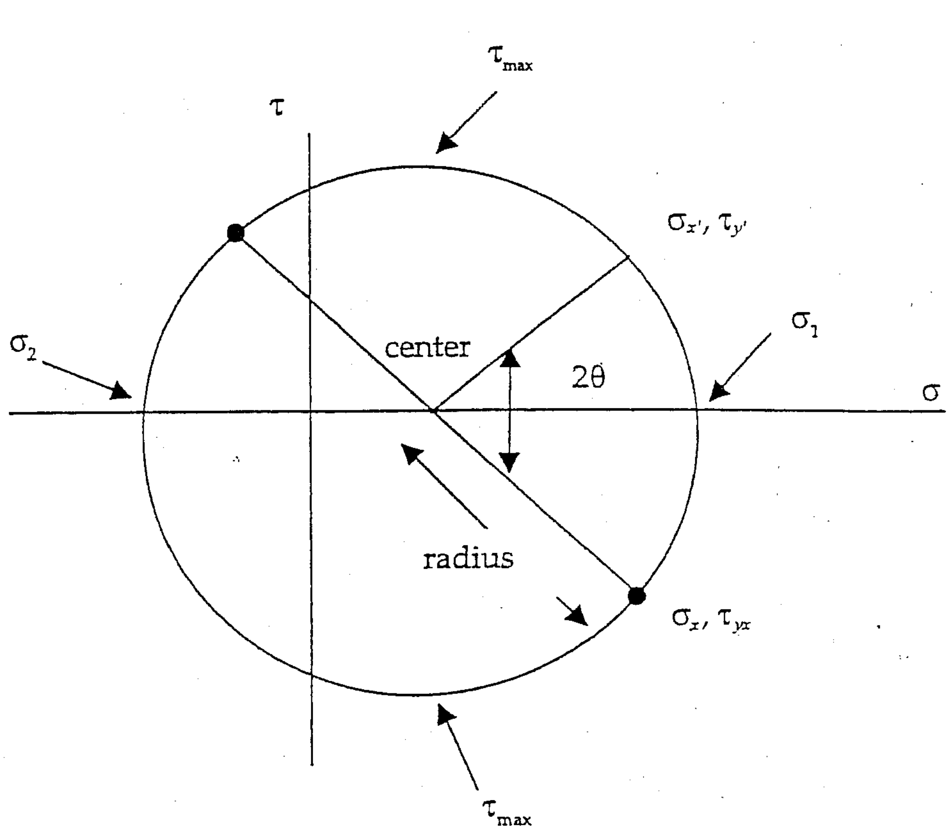

Fig. 5 Mohr's circle for two-dimensional stress transformation

Cubic Equation Calculator

Input MUST have the format: $AX^3 + BX^2 + CX + D = 0$

EXAMPLE: If you have the equation: $2X^3 - 4X^2 - 22X + 24 = 0$

then you would input: A= 2 B= -4 C= -22 D=24

Click E N T E R and your answers should be 4, -3 and 1

A= 1 B= -2.096 C= -8.27 D= 0

E N T E R

X_1= 4.10876853094121

X_2= -2.01276853094121

X_3= 0

To see the method for solving cubic equations, click HERE

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ENGINEERING DESIGN FILE

EDF- 096 – O13
Rev. No.

EDF Title: PM-2A Half Tank Cover

Project No.: 2000-096	Project Title: PM-2A Tanks and Burn Pits RD/RAWP

Problem Statement:

A cover is to be designed for the PM-2A half tank to prevent the debris in the tank from being scattered around the work site but allow access to the tank to remove the sludge and clean the tank. The access opening is to be five feet wide and allow access for the full width of the tank. The opening is to be designed so that it will move along the tank to sequentially provide access for removing the sludge and cleaning the tank over the full length of the tank.

Summary of Conclusions:

The designed cover is shown on the attached sketches and on the Drawing, Half Tank Cover, included with the design drawings for the project. The design utilizes a 20 mil plastic cover fixed at each end with a cart in between with reels spaced to provide a 5 feet opening between them. The design is for one reel to wind up the cover from one end of the tank and the other reel to unwind the cover from the other end with the cart and 5 foot space traveling along the tank.

Review and Approval Signatures:

	R/A	Printed Name	Signature	Date
Prepared by:		Herbert L Maglebey	Herbert L Maglebey	7/10/03
Checked by:		KEVIN SHABER	[signature]	10/20/03
Approval:		GARY METHAM	[signature]	10/21/03

Distribution:

Professional Engineer's Stamp (if required)

REGISTERED PROFESSIONAL ENGINEER
Herbert L Maglebey
2494
10/21/03
STATE OF IDAHO
HERBERT L. MAGLEBY

Problem Statement:

A cover is to be designed for the PM-2A half tank to prevent the debris in the tank from being scattered around the work site but allow access to the tank to remove the sludge and clean the tank. The access opening is to be five feet wide and allow access for the full width of the tank. The opening is to be designed so that it will move along the tank to sequentially provide access for removing the sludge and cleaning the tank over the full length of the tank.

Assumptions:

A 20 mil plastic cover that overlaps the tank sides at least 9 inches will provide adequate containment. The radiation levels will be low enough that personnel will have access to install the cover system and to operate the cover system.

References:

Calculations / Analysis:

The design utilizes a 20 mil plastic cover fixed at each end with a cart in between with reels spaced to provide a 5 feet opening between them. The design is for one reel to wind up one end of the cover and the other to unwind the other end with the cart and the 5 foot space traveling along the tank. The cart frame is made with 6 inch light weight channels and has two foot wide platforms on each end of the five foot opening. The platforms use a 1/4 inch thick aluminum cover to provide torsional rigidity. The platforms are designed to support a 200 lb man standing at their centers. Calculations are attached.

Commercially available swimming pool cover reels are used to wind and unwind the cover. The cart is designed with polyurethane flange wheels that support the cart and roll along the half tank edge. Each corner of the cart has a set of two wheels spaced about 1 foot apart to accommodate any irregularities in the half tank edges. The wheels are flanged on one side and the flanges will be positioned on the outside of the tank to keep the cart correctly positioned over the half tank.

The weight of the cart without the plastic cover is about 500 lbs with only about 62.5 lbs per wheel giving confidence that even a deteriorated tank can easily support the cart. Also, the feature of the two closely spaced wheels at each corner allows for one wheel to lose support if the tank has deteriorated and the other wheel to pick up the load. When the first wheel reaches solid support it will carry the load while the second travels over the deteriorated area.

The plastic cover is to be fixed at each end of the half tank. The structure to support and fix the plastic cover at the ends of the tank is shown on EDF 096 – 014.

ATTACHMENTS

Design Sketches
Design Calculations
Vendor Data

DESIGN SKETCHES

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JOB PM-2A Tank Decon Cover,

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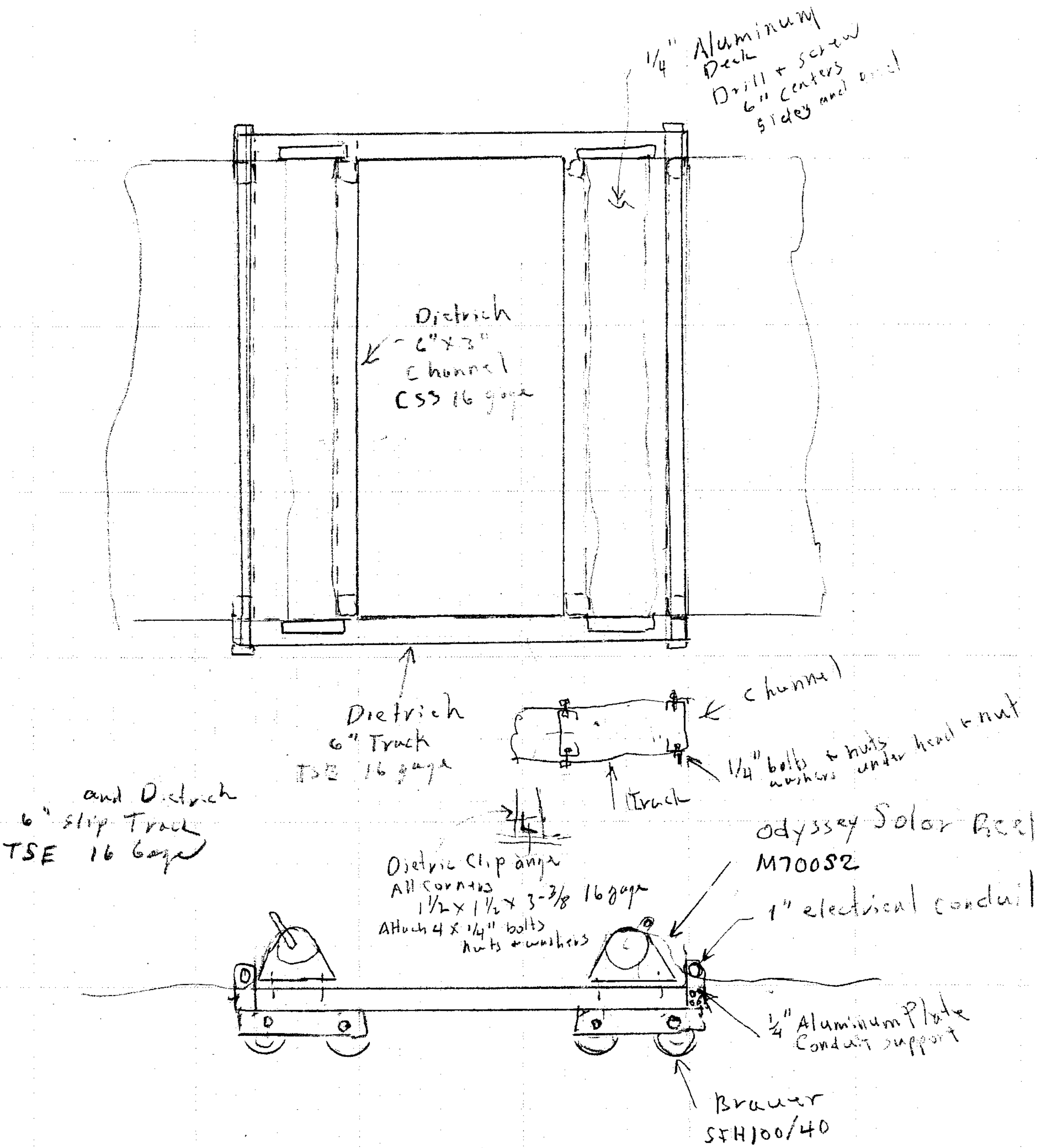

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JOB PM-2A Decon Cover

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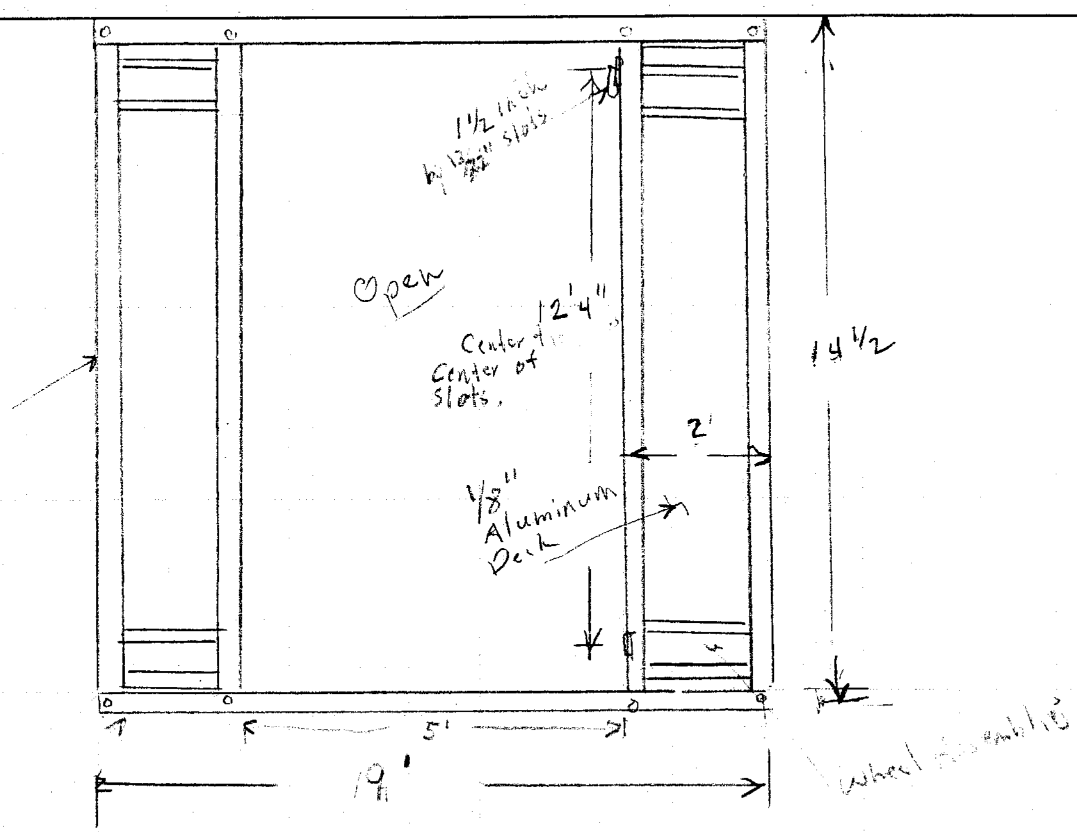
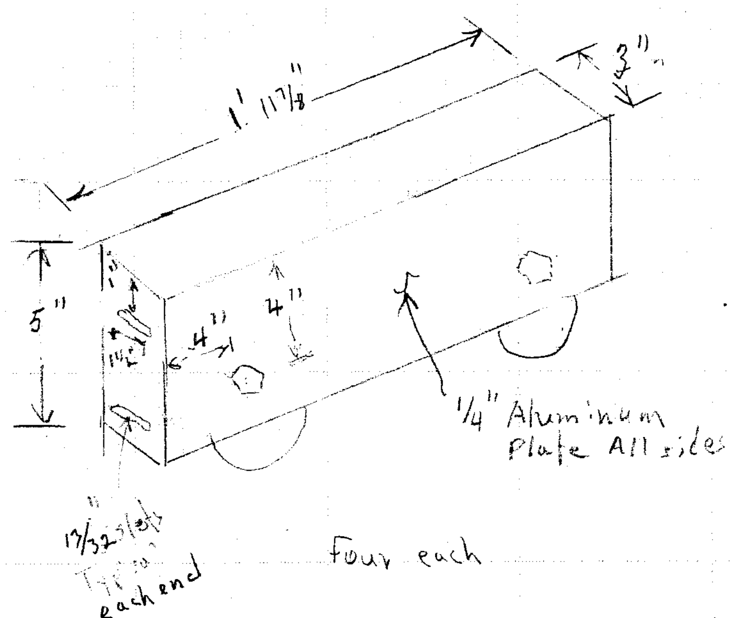
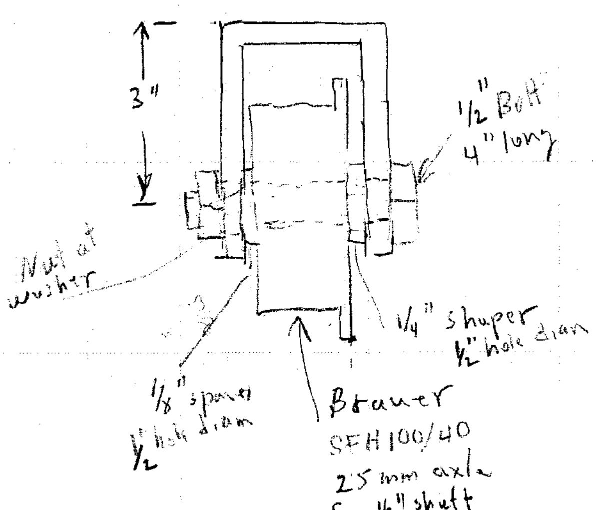
Dietrich
6"x3" C Stud
CCS 16 gage
Typical 4



Dietrich
6" Track
TSB 16 gage
Typical 2



wheel detail



Attach with 3/8 bolts and washers under head and nut

DESIGN CALCULATIONS

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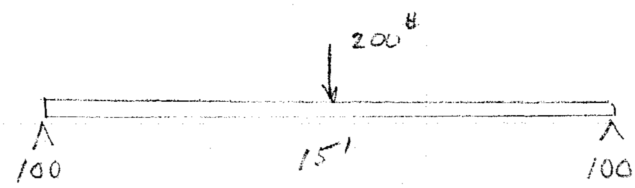
SCALE ______

For 200# at center of 15' beam



$M = 100 \times 7.5 \times 12 = 9.0 \times 10^3$ in-lb

$\sigma = 1/2\, \sigma_y = 18{,}000$ psi Allowable stress (Conservative limit)

$\sigma = \frac{Mc}{I} = \frac{M}{S}$

$S = \frac{M}{\sigma} = \frac{9 \times 10^3}{18 \times 10^3} = 0.500$ $\qquad \frac{\text{in-lb}}{\text{lb/in}^2} = \text{in}^3$

Dietric 6x3" C stud 16 gage $S = 1.509$ in³ is more than adequate

Dietric 6x3" C stud 16 gage
$S_y = 1.509$ in³ weight per foot 2.516

Total weight of cart

6x3 CSTUDS	$4 \times 14.5 \times 2.516 + 2 \times 9 \times 1.557$ =	17.5 lb
1/4" Aluminum Deck	$2 \times 2 \times 14.5 \times \frac{0.125}{12} \times 165$ =	100
wheels	8×2.7 kg $\times 2.2$ lb/kg =	50
Reels	2×75	150
Miscellaneous brackets etc.	25 lb.	25
		500 lbs

Plus weight of one cover

VENDOR DATA

Solar Cover Reels \ Pool Liners 2003

\nd Water Tube
ıp 2

r Cover Step 2

Odyssey Solar Reels

M400	Deluxe Residential 12' - 20' w/casters	504.00
M700S2	Commercial Reel 21' - 26'	870.00
620	Bearing Race (M700S2)	27.33
OD101	Extra Strap Kit	58.91

Above Ground Reels

M818	Above Ground Reel 12' - 18'	286.50
M824	Above Ground Reel 19'-24'	330.00
OD101	Extra Strap Kit	58.91

Above Ground Liners

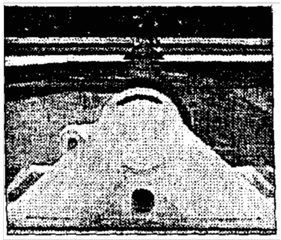
10 Mil, Splasher Pool		
LI1236	12' x 36"	83.12
20 Mil, Above Ground		
LI1248HD	12' x 48"	130.77
LI1548HD	15' x 48"	173.64
LI1848HD	18' x 48"	257.10
LI2148HD	21' x 48"	281.02
LI2448HD	24' x 48"	301.56
LI2748HD	27' x 48"	421.96
LI15X30X48HD	15' x 30' x 48" Oval	348.75
LI16X32X48HD	16' x 32' x 48" Oval	426.78
LI2448X72HDEXP	24' Expandable Liner	181.66

Plastimaid Vinyl Repair Kits

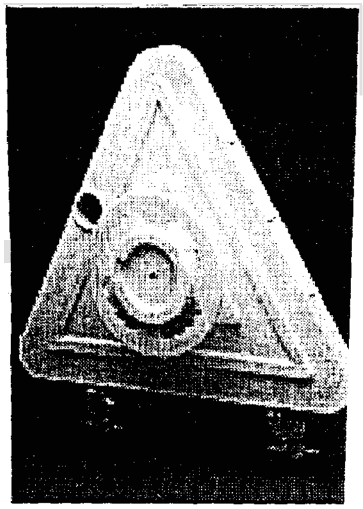
5870	Patch Glue 12oz.	23.94
5875	Deluxe Repair Kit	17.31
5878	Patch Kit - 4oz.	16.65
5882	Patch Kit - 2oz.	8.61
Aquality Vinyl Patch Kit		
AQ10012	Patch-N-Seal Kit	13.71

Above Ground Liner Coping

AGPC	Liner Coping 53" Long	3.79

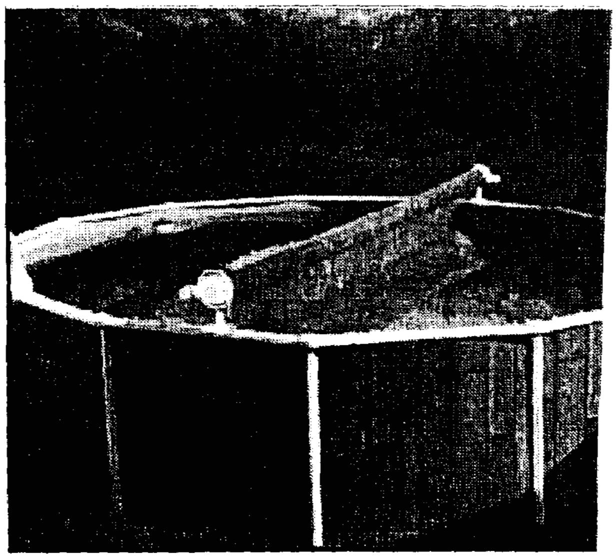


M400 Deluxe Residential

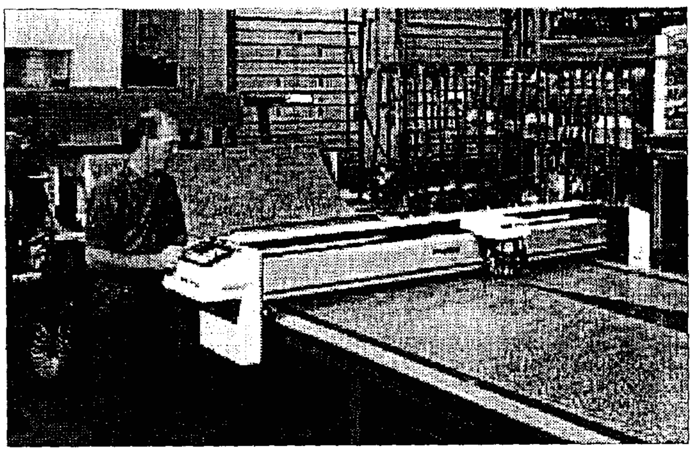


M700S2
Commercial Reel

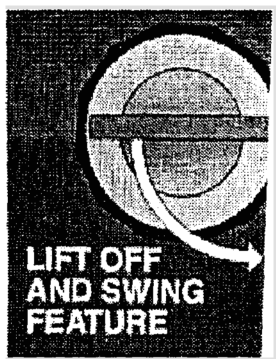
M400 Deluxe Residential



M818 & M824
Above Ground Reel

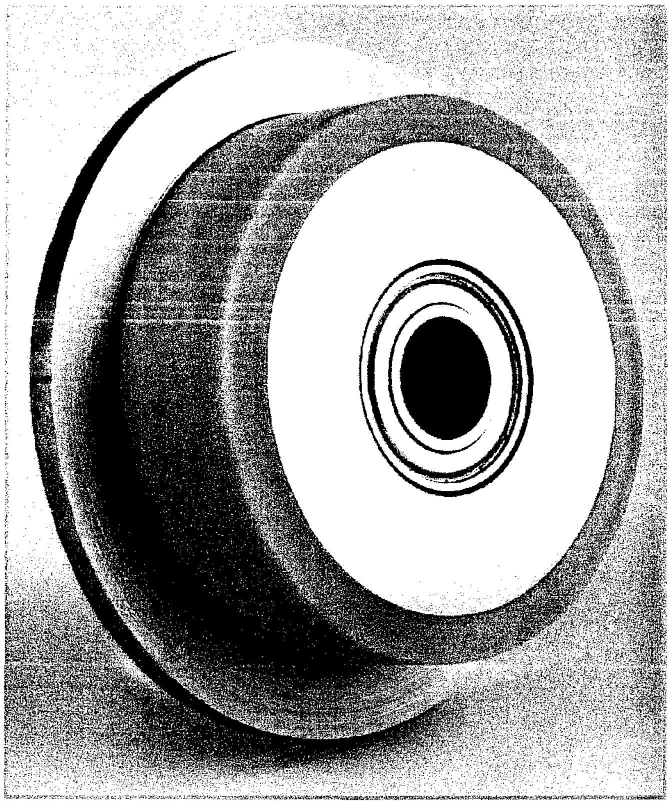


M818 & M824
Above Ground Reel



M 818

Polyurethane Tyred Single-flanged Rail Wheels



Standard wheel features flanges with a 5° angle and a 'flat tread' (ie tread parallel to the wheel axis) for running on flat top rail. Polyurethane is resilient, durable material, resistant to abrasion and to many common chemicals. Polyurethane tyred wheels are capable of carrying heavy loads and of transmitting driving forces

MATERIAL: Wheel Centre - Steel to BS970: Part 1: 1983: 080 M40
Tyre - Polyester Based Polymer of 92° ± 3° A Shore Hardness

OPERATING TEMPERATURE RANGE:
-20°C to + 60°C (115°C for limited use)

PLEASE SPECIFY IF OPERATING IN HIGH HUMIDITY.
Anti-hydrolysis polyurethane is recommended for use in an operating environment of high humidity.

Polyurethane to the above hardness used on these wheels is Vulkollan, a high quality material that provides superior performance in most applications.

Should the mechanical properties of Vulkollan be inappropriate for the application, alternative grades of *Polyurethane can be produced to meet the requirements.* Polyurethane can be bonded onto most metal centres including aluminium, titanium, stainless steel and various ferrous and non-ferrous alloys.

The ' Maximum Load Rating' given for each wheel assumes the full tread width is in contact with the rail. In practice full contact with the rail across the tread width is rarely achieved due to:-

a) Flange to rail clearance
b) Wheel Overhang
c) Rail Corner Radii

For calculation of the 'Maximum Allowable Load' see 'Design Data' Para 6.1

In addition the 'Maximum Load Rating' given for each wheel is for operation under ideal conditions.

Load factors must be applied according to the anticipated working conditions - see 'Design Data' Para 4.1

Alternative Bore/Bearing diameters and alternative bearing types (i.e) bronze brushes, self lubricating brushes, etc.) are available to order - see page 17-18.

For technical information covering load factors, inertial and rolling resistance, chemical resistance, coefficients of friction between wheel and track and keyway dimensions, see 'Data Design' Index on page 12.

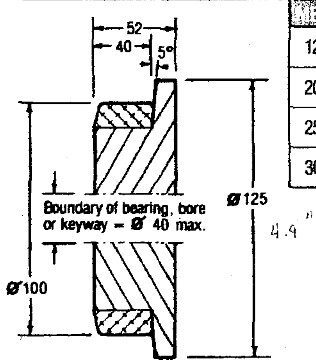
FULL PART NUMBER FOR ORDERING				
Axle Ø	**Plain Bore**	**Plain Bore Keywayed**	**Ball Bearing**	**Taper Roller Bearing**
METRIC AXLE Ø				
12		SFH100/40/KM 12	SFH100/40/BJM 12	
20		SFH100/40/KM 20	SFH100/40/BJM 20	
25		SFH100/40/KM 25	SFH100/40/BJM 25	
30		SFH100/40/KM 30		

WHEEL TYPE:
SFH100/40

Maximum load rating: 500kg

See 'Design Data' paras 4.1 and 6.1 for 'Maximum Allowable Load'.

Approximate weight: 2.7kg



Wheels fitted with ball journals are pre-lubricated, double shielded. Alternatively greasing can be through the axle – state if this option is required when ordering

+44 (0) 1908 374 022 BRAUER FAX: +44 (0) 1908 641 628

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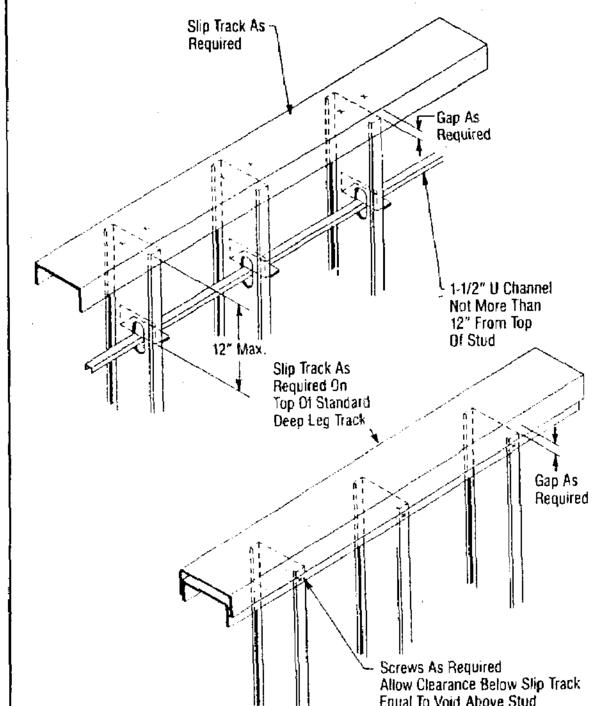
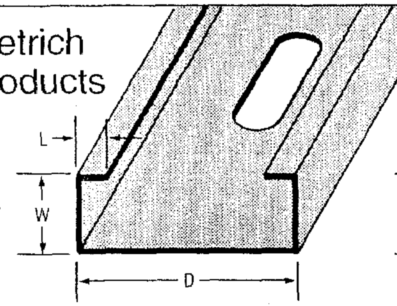
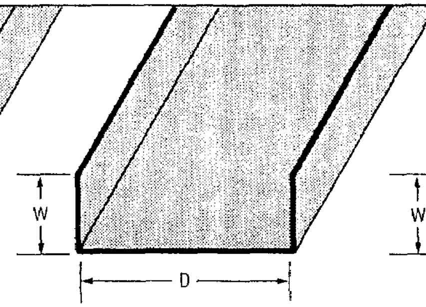
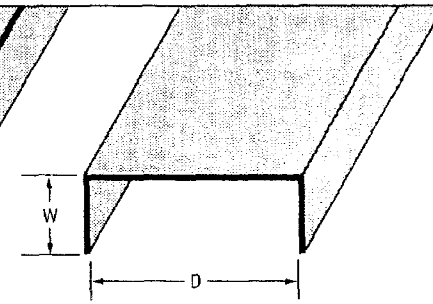


SLIP TRACK DETAILS

Dietrich Products







C STUDS

CODES	GAGES	W	L	D
CWN	20-14	1-3/8"	3/8"	2-1/2"-8"
CSJ	20-10	1-5/8"	1/2"	2-1/2"-16"
CSW	20-10	2"	5/8"	3-5/8"-16"
CSE	20-10	2-1/2"	5/8"	3-5/8"-16"
CSS	20-10	3"	1"	6"-16"
CSX	20-10	3-1/2"	1"	6"-16"

TRACK

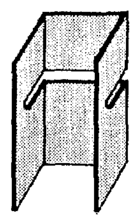
CODES	GAGES	W	D
TSA	20-10	1"	2-1/2"-16"
TSB	20-10	1-1/4"	2-1/2"-16"

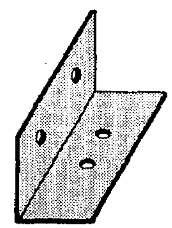
SLIP TRACK

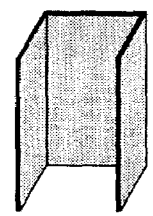
CODES	GAGES	W	D
TSF	20-10	1-1/2"	2-1/2"-16"
TSC	20-10	2"	2-1/2"-16"
TSD	18-10	2-1/2"	2-1/2"-16"
TSE	16-10	3"	2-1/2"-16"
TSG	14-10	3-1/2"	3-5/8"-16"

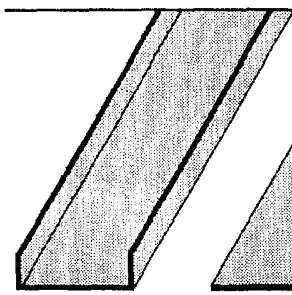
NOTE: Codes are for single track application. Double track applications require a special formed wider track. Consult your local plant for double track applications.

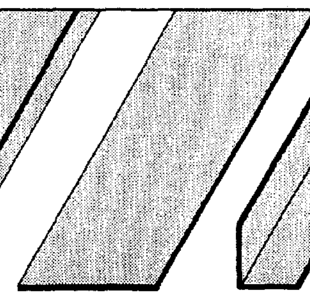
Accessories

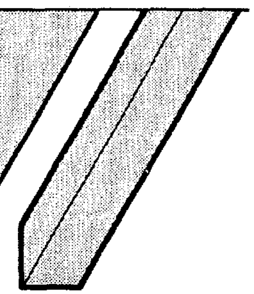

SLIDE CLIP


CLIP ANGLE


WEB STIFFENER


U CHANNEL


FLAT STRAP


ANGLE

Physical Structural Definitions

Area = Gross Area
M_x = Fully braced allowable x-axis moment
I_x = Moment of inertia about x-axis
S_x = Section modulus about x-axis
R_x = Radius of gyration about x-axis
I_y = Moment of inertia about y-axis
S_y = Section modulus about y-axis
R_y = Radius of gyration about y-axis
X_0 = Distance from shear center to centroid along principal y-axis
J = St. Venant torsional constant
C_w = Warping torsion constant
R_0 = Polar radius of gyration about shear center
β = $1-(X_0/R_0^2)$

Physical Structural Properties–6" C Studs

DIETRICH

MEMBER							GROSS SECTION PROPERTIES							EFFECTIVE SECTION PROPERTIES 33 KSI			EFFECTIVE SECTION PROPERTIES 50 KSI			TORSIONAL PROPERTIES				
CODE	GAGE	Flange (in.)	Lip (in.)	Design Thickness (in.)	Minimum Delivered Thickness (in.)	Weight (lb./ft.)	Area (in.^{2})	I_x (in.^{4})	S_x (in.^{3})	R_x (in.)	I_y (in.^{4})	S_y (in.^{3})	R_y (in.)	I_x (in.^{4})	S_x (in.^{3})	M_x (in.-lb.)	I_x (in.^{4})	S_x (in.^{3})	M_x (in.-lb.)	X_o (in.)	J x 1000 (in.^{4})	C_w (in.^{6})	R_o (in.)	β BETA
CWN	20	1-3/8	3/8	0.0346	0.0329	1.047	0.320	1.597	0.532	2.234	0.070	0.065	0.466	1.597	0.513	10145				-0.820	0.128	0.496	2.425	0.886
	18	1-3/8	3/8	0.0451	0.0428	1.351	0.413	2.043	0.681	2.224	0.087	0.082	0.460	2.043	0.681	15016				-0.812	0.279	0.625	2.412	0.887
	16	1-3/8	3/8	0.0566	0.0538	1.682	0.514	2.519	0.840	2.214	0.105	0.098	0.452	2.519	0.840	18991	2.519	0.819	27587	-0.804	0.550	0.758	2.398	0.888
	14	1-3/8	3/8	0.0713	0.0677	2.091	0.639	3.094	1.031	2.200	0.125	0.117	0.443	3.094	1.031	24034	3.094	1.031	35649	-0.793	1.082	0.911	2.380	0.889
CSJ	20	1-5/8	1/2	0.0346	0.0329	1.132	0.346	1.808	0.603	2.286	0.118	0.097	0.583	1.808	0.538	11516				-1.088	0.138	0.855	2.598	0.825
	18	1-5/8	1/2	0.0451	0.0428	1.461	0.447	2.316	0.772	2.277	0.148	0.123	0.577	2.316	0.772	16764				-1.080	0.302	1.082	2.585	0.826
	16	1-5/8	1/2	0.0566	0.0538	1.821	0.557	2.862	0.954	2.268	0.181	0.149	0.570	2.862	0.954	21175	2.862	0.928	30753	-1.071	0.595	1.318	2.572	0.826
	14	1-5/8	1/2	0.0713	0.0677	2.266	0.693	3.524	1.175	2.255	0.218	0.180	0.561	3.524	1.174	26767	3.524	1.174	39811	-1.061	1.173	1.595	2.555	0.828
	12	1-5/8	1/2	0.1017	0.0966	3.174	0.970	4.841	1.614	2.234	0.287	0.237	0.544	4.841	1.613	38533	4.841	1.613	57017	-1.034	3.344	2.102	2.521	0.832
	10	1-5/8	1/2	0.1242	0.1180	3.833	1.171	5.773	1.924	2.220	0.333	0.275	0.533	5.773	1.924	47354	5.773	1.924	69858	-1.013	6.025	2.423	2.498	0.835
CSW	20	2	5/8	0.0346	0.0329	1.246	0.381	2.090	0.697	2.343	0.211	0.148	0.745	2.051	0.610	12049				-1.474	0.152	1.583	2.867	0.736
	18	2	5/8	0.0451	0.0428	1.609	0.492	2.683	0.894	2.336	0.268	0.188	0.739	2.683	0.874	17261				-1.467	0.333	2.011	2.855	0.736
	16	2	5/8	0.0566	0.0538	2.006	0.613	3.322	1.107	2.327	0.329	0.230	0.732	3.322	1.107	24082	3.322	1.004	30057	-1.459	0.656	2.462	2.842	0.737
	14	2	5/8	0.0713	0.0677	2.499	0.764	4.099	1.366	2.316	0.400	0.280	0.723	4.099	1.366	30395	4.099	1.337	44391	-1.448	1.293	2.995	2.826	0.737
	12	2	5/8	0.1017	0.0966	3.507	1.072	5.656	1.885	2.297	0.536	0.375	0.707	5.656	1.885	43625	5.656	1.885	64788	-1.421	3.694	3.995	2.792	0.741
	10	2	5/8	0.1242	0.1180	4.239	1.296	6.762	2.254	2.284	0.628	0.440	0.696	6.762	2.253	53499	6.762	2.253	79242	-1.399	6.663	4.646	2.768	0.744
CSE	20	2-1/2	5/8	0.0346	0.0329	1.359	0.415	2.399	0.800	2.403	0.359	0.206	0.930	2.267	0.636	12577				-1.905	0.166	2.650	3.204	0.647
	18	2-1/2	5/8	0.0451	0.0428	1.756	0.537	3.082	1.027	2.396	0.458	0.263	0.923	3.064	0.918	18149				-1.897	0.363	3.377	3.193	0.647
	16	2-1/2	5/8	0.0566	0.0538	2.192	0.670	3.822	1.274	2.389	0.563	0.323	0.917	3.822	1.159	22909	3.636	1.069	32018	-1.889	0.716	4.148	3.180	0.647
	14	2-1/2	5/8	0.0713	0.0677	2.733	0.835	4.726	1.575	2.379	0.688	0.395	0.908	4.726	1.522	33141	4.667	1.343	40195	-1.878	1.414	5.068	3.164	0.648
	12	2-1/2	5/8	0.1017	0.0966	3.840	1.174	6.540	2.180	2.361	0.932	0.535	0.891	6.540	2.179	49029	6.540	2.090	70069	-1.851	4.045	6.818	3.130	0.650
	10	2-1/2	5/8	0.1242	0.1180	4.646	1.420	7.834	2.611	2.349	1.100	0.631	0.880	7.834	2.610	59976	7.834	2.589	88453	-1.828	7.302	7.981	3.104	0.653
CSS	20	3	1	0.0346	0.0329	1.557	0.476	2.831	0.944	2.439	0.656	0.340	1.174	2.489	0.634	12533				-2.619	0.190	5.724	3.767	0.516
	18	3	1	0.0451	0.0428	2.014	0.616	3.644	1.215	2.433	0.841	0.435	1.169	3.436	0.997	19704				-2.613	0.417	7.317	3.756	0.516
	16	3	1	0.0566	0.0538	2.516	0.769	4.526	1.509	2.426	1.039	0.537	1.162	4.486	1.366	26999	4.308	1.262	37788	-2.605	0.822	9.020	3.745	0.516
	14	3	1	0.0713	0.0677	3.141	0.960	5.608	1.869	2.417	1.279	0.661	1.154	5.608	1.841	36376	5.597	1.701	50920	-2.596	1.625	11.072	3.730	0.516
	12	3	1	0.1017	0.0966	4.422	1.351	7.790	2.597	2.401	1.753	0.906	1.139	7.790	2.595	57233	7.790	2.564	84479	-2.570	4.658	15.030	3.697	0.517
	10	3	1	0.1242	0.1180	5.357	1.637	9.353	3.118	2.390	2.085	1.077	1.129	9.353	3.115	69959	9.353	3.115	104299	-2.547	8.420	17.708	3.671	0.519
CSX	20	3-1/2	1	0.0346	0.0329	1.670	0.511	3.139	1.046	2.480	0.939	0.423	1.356	2.661	0.652	12876				-3.085	0.204	8.130	4.184	0.456
	18	3-1/2	1	0.0451	0.0428	2.162	0.661	4.043	1.348	2.474	1.205	0.543	1.351	3.697	1.044	20634				-3.079	0.447	10.408	4.174	0.456
	16	3-1/2	1	0.0566	0.0538	2.701	0.826	5.026	1.675	2.467	1.492	0.671	1.344	4.863	1.442	28491	4.643	1.324	39634	-3.071	0.883	12.851	4.163	0.456
	14	3-1/2	1	0.0713	0.0677	3.374	1.031	6.234	2.078	2.459	1.840	0.827	1.336	6.234	1.947	38465	6.070	1.760	52689	-3.062	1.746	15.806	4.148	0.455
	12	3-1/2	1	0.1017	0.0966	4.754	1.453	8.675	2.892	2.443	2.533	1.138	1.320	8.675	2.888	62765	8.675	2.537	75972	-3.036	5.008	21.543	4.115	0.456
	10	3-1/2	1	0.1242	0.1180	5.763	1.761	10.425	3.475	2.433	3.022	1.358	1.310	10.425	3.473	76680	10.425	3.336	110054	-3.013	9.059	25.455	4.088	0.457

6" Track

TSB	20	1-1/4" LEG		0.0346	0.0329	0.956	0.292	1.393	0.459	2.183	0.034	0.032	0.340	1.239	0.326	6435				-0.524	0.117	0.231	2.271	0.947
	18	1-1/4" LEG		0.0451	0.0428	1.242	0.379	1.808	0.594	2.183	0.043	0.041	0.338	1.688	0.505	9970				-0.522	0.257	0.298	2.270	0.947
	16	1-1/4" LEG		0.0566	0.0538	1.557	0.476	2.267	0.742	2.183	0.054	0.052	0.336	2.206	0.671	13257				-0.520	0.509	0.371	2.269	0.948
	14	1-1/4" LEG		0.0713	0.0677	1.953	0.597	2.843	0.926	2.182	0.067	0.064	0.334	2.843	0.891	17611				-0.517	1.011	0.461	2.267	0.948
	12	1-1/4" LEG		0.1017	0.0966	2.778	0.849	4.050	1.306	2.184	0.092	0.089	0.328	4.050	1.305	29367				-0.509	2.926	0.643	2.267	0.950
	10	1-1/4" LEG		0.1242	0.1180	3.389	1.036	4.955	1.586	2.187	0.109	0.107	0.324	4.955	1.585	36426				-0.501	5.327	0.773	2.267	0.951

NOTE: Reference typical notes on page 4.

intrepid technology & resources incorporated

ENGINEERING DESIGN FILE

EDF- 096-14
Rev. No.

EDF Title: PM-2A Half Tank Positive Air Flow System

Project No.: 2000-096	Project Title: PM-2A Tanks and Burn Pits RD/RAWP

Problem Statement:

Design a system that will provide positive air flow during the sludge removal of the PM-2A half tanks. The air flow is to be through the 5' X 12' 6" work space opening, through the half tank, out the end of the half tank, though a HEPA filter and exhausted to the atmosphere.

Summary of Conclusions:

The designed system is shown in the attached Design Sketches. The design uses an end plate on the half tank to support the end of the plastic cover and provide a connection for the duct work that leads to a HEPA filter. An axial in line fan installed in the outlet duct of the HEPA filter provides the air flow of 1350 cfm through the half tank and filter and exhausts to the atmosphere. The fan is capable of providing the 1350 cfm for up to 73% increase in filter resistance and will still provide 1000 cfm for a 118% increase in filter resistance.

Review and Approval Signatures:

	R/A	Printed Name	Signature	Date
Prepared by:		Herbert L Magleby	Herbert L Magleby	7/10/03
Checked by:		KEVIN SHABER	[signature]	10/20/03
Approval:		GARY MECHAM	[signature]	10/21/03

Distribution:

Professional Engineer's Stamp (if required)

REGISTERED PROFESSIONAL ENGINEER
Herbert L Magleby
2494
10/21/03
STATE OF IDAHO
HERBERT L. MAGLEBY

EDF Title: PM-2A Half Tank Air Flow		EDF- 096 - 014
Project No.: 2000-096		Rev No.:
Project Title: PM-2A Tanks and Burn Pits RD/RAWP		Page 2 of 2
Prepared by: Date:	Checked by:	Date:

Problem Statement:

Design a system that will provide positive air flow during the sludge removal of the PM-2A half tanks. The air is to flow into the tank through the 5' X 12' 6" work space opening, through the half tank, out at the end of the half tank, though a HEPA filter and exhausted to the atmosphere.

Assumptions:

An air flow of ¼ miles per hour through the half tank will provide adequate positive air flow.

References:

Crane Technical Paper No. 410, Flow of Fluids Through Valves, Fittings, and Pipe.

Calculations / Analysis:

The design is shown on the attached Design Sketches Sheets 1 and 2 and on the Drawing, Half Tank Positive Air Flow, included with the design drawings for the project. The Design includes an 18 inch wide aluminum plate across the half tank at the end of the tank where the vacuum system is located. The plate has a fixed channel on the bottom across the end with a sponge rubber seal. Movable channels with sponge rubber seals are attached to the bottom of the plate across the 18 inch dimension along the half tank sides. The design scheme is to push the plate up snug to seal the end then move the two side channels in snug and secure them in place with bolts in slots that extend up through the aluminum plate. A plate with bolts is provided on the other edge of the plate across the open tank to secure the end of the plastic cover. This scheme will provide a seal for the plate to the tank and secure it in place and will secure the end of the plastic cover.

A 10 inch hole with a stub is located in the center of the plate to provide a connection for the flexible duct that connects to a HEPA filter. A rigid duct is used to connect the outlet of the filter to an in-line fan. The air flow, then, is in through the work space in the plastic cover, along the half tank to the end, out the end through the 10 inch duct, to the HEPA filter, out of the HEPA filter through the in-line fan and exhausted to the atmosphere. The exhaust is directed up at an angle to avoid impacting the construction site and creating dust. A flexible duct, MOPECO M-30646, is used for the connection from the half tank cover plate to the HEPA filter to allow the plate to be moved to the second tank and moved to provide access to the ends of the half tanks for sludge removal and half tank cleaning as described below.

The HEPA filter chosen for the design is the standard Flanders G Series 24" X 24" housing with a GGF 24" X 24 " X 11 ½" deep filter. The filter is rated for a 1500 cfm with a 1.3" w.g. pressure differential. The axial in-line fan is an ACME In-Line Airfoil Centrifugal Fan Model 2115 with a partial width wheel that is rated at 3.0" w.g. at 1350 cfm. Calculations were made of the system head loss that show that the Fan Model 2115 is capable of delivering 1350 cfm with a clean new filter and will be able to deliver 1350 cfm for up to 73% increase in filter resistance. The fan will still deliver 1000 cfm with a 118% increase in filter resistance. The 1000 cfm will still provide good positive air flow and the design is acceptable. The attached Design Calculations show the air flow calculations.

A similar 18 inch wide cover plate will be used to secure the end of the plastic cover at the other end of the half tank. This plate will not need the stub for the 10 inch air duct.

For removing the sludge and cleaning the half tanks at the ends under the 18 inch wide end plates, the side seals can be moved out and the plates lifted and slide toward the center of the tanks to allow access. The system can continue to operate with an end plate moved and provide some positive air flow. With the end plate moved at the far end, air will still be drawn down the tank and out through the filter by the fan and exhausted to the atmosphere. The flexible duct allows the cover to be lifted and moved on the end near the HEPA filter and air from the working area at the end of the tank will be drawn through the filter by the fan and exhausted to the atmosphere.

DESIGN SCKETCHES

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JOB PM-2A Half Tank Air Flow
SHEET NO. Design Sketch 1 OF
CALCULATED BY Lowell DATE 1/3/03
CHECKED BY DATE
SCALE

1 Cover See Detail Sheet 2

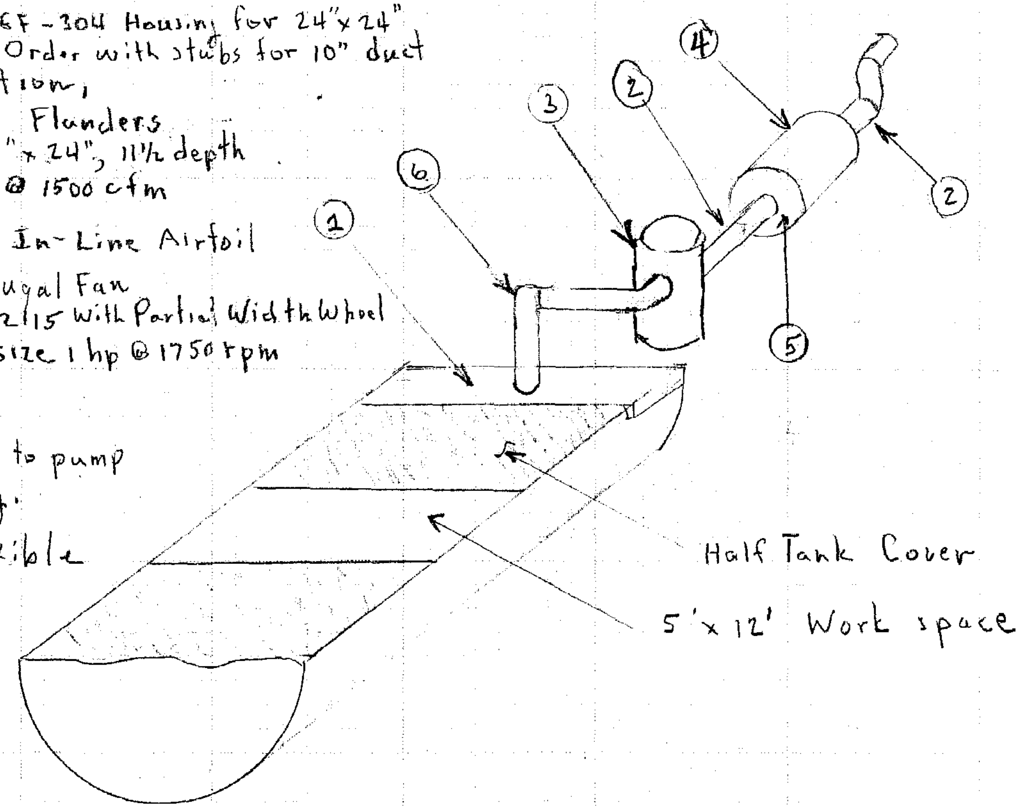
2, 10" Duct

3, HEPA Filter
Flanders G Series
CIF-GGF-304 Housing for 24"x24" filters. Order with stubs for 10" duct connection,
Filters Flanders
GGF 24"x24", 11½ depth
1.3"Wg @ 1500 cfm

4. ACME In-Line Airfoil
Centrifugal Fan
Model 2/15 with Partial Width Wheel
Motor size 1 hp @ 1750 rpm

5. Flange
10" duct to pump housing.

6, 10" Flexible Duct



Positive Air Flow System
PM-2A Tank Cleaning

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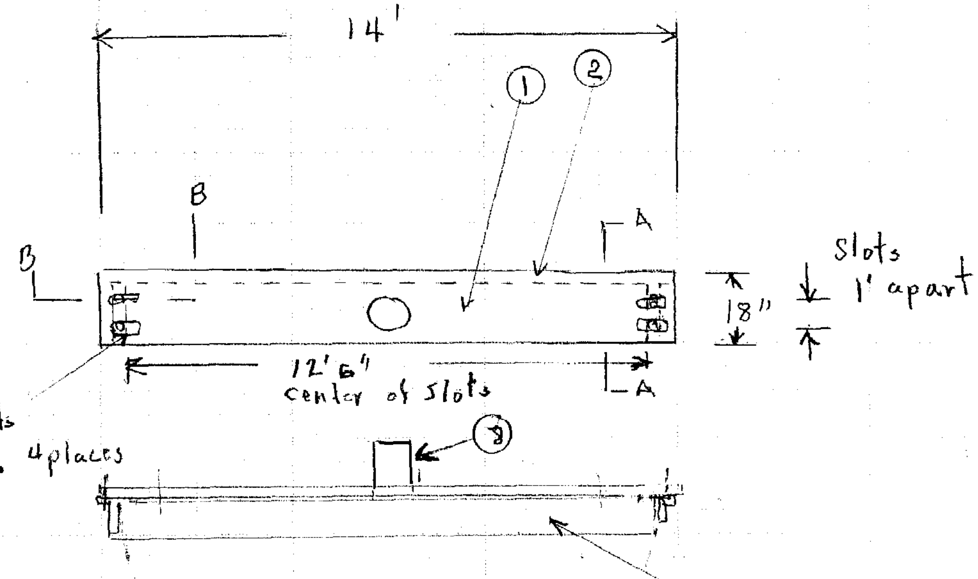
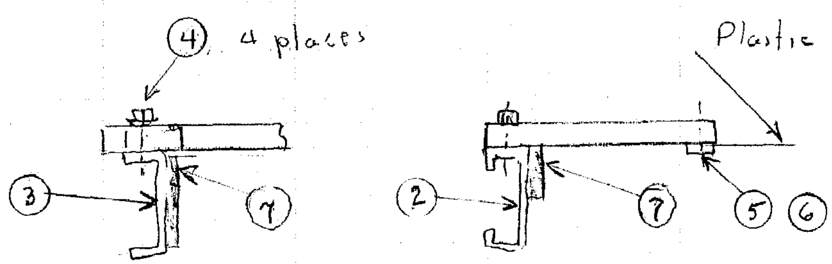
JOB PM-2A Half Tank Air Flow
SHEET NO. Design Sketch 2 OF
CALCULATED BY Lowell DATE 9/7/03
CHECKED BY DATE
SCALE

1 3/8 Aluminum Plate
2. Dietrich 6" C stud CSS 16 gage
3. Dietrich U channel CHN3 2" 16 gage
4. 3/8" x 1" bolts washers and nuts
5 Dietrich 1" flat strap, 12'6"
6 1/4" x " bolt and nuts
7 2" x 1/2 sponge rubber strip or similar seal strip.
8. 10" stub for 10" air duct connection





PM-2A Half Tank End Air Flow Connection and End Plastic Cover Support
(Other End Same Except without 10" stub for duct connection)

DESIGN CALCULATIONS

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JOB PM-2A Half Tank Air Flow.

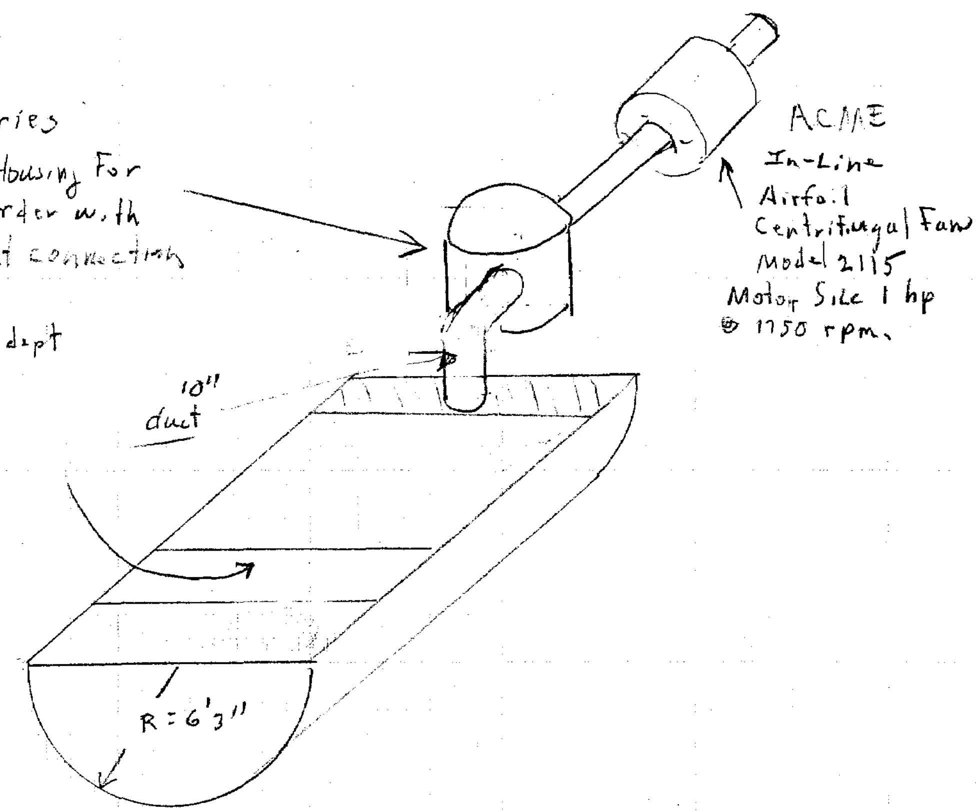
SHEET NO. 0 OF

CALCULATED BY Lowell DATE 7/3/03

CHECKED BY DATE

SCALE

HEPA Filter
Flanders G Series
CIF-GGF-304 Housing For
24"x24" filters. Order with
Stubs for 10" duct connection
Filter Flanders
GGF 24"x24", 11½ dept
1.3"wg @ 1500 cfm



Assme flow rate in Tank to be 1/4 mph

$$v = 0.25 \frac{mi}{hr} \; 5280 \frac{ft}{mi} \; \frac{hr}{3600\,sec} = 0.367\ ft/sec$$

Flow area of tank

$$A = \frac{1}{2} \pi R^2 = \frac{1}{2} \pi (6.25)^2 = 61.36\ ft^2$$

Flow volume

$$V_o = 0.367 \frac{ft}{sec} \; 60 \frac{sec}{min} \; 61.36\ ft^2 = 1{,}350\ ft^3/min$$

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JOB PM-2A Half Tank Air Flow
SHEET NO. 1 OF
CALCULATED BY Lowell DATE 7/8/03
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SCALE

Determine pressure loss through duct and fittings

Reference Flow of Fluids through Valves, Fittings and pipe.
by the Engineering Division Crane Co. Chicago.
Technical Paper No. 410 Copyright 1957. Crane Co.

Page 1-6

The Darcy equation

$$h_L = \frac{fL}{D}\frac{v^2}{2g} \quad \text{feet of liquid}$$

with suitable restrictions may be used when gases and vapors (compressible fluids) are being handled.

Page 1-7

If the calculated pressure drop ($P_1 - P_2$) is than about 10% of the inlet pressure P_1, reasonable accuracy will be obtained if the specific volume used in the formula is based upon either the upstream or downstream conditions, whichever is known.

For our case the inlet pressure is atmospheric. 10% of atmospheric is

$$\Delta h_{max} = 0.10 \times 14.7 \frac{lb}{in^2} \; 144 \frac{in^2}{ft^2} \; \frac{ft^3}{62.4\,lb} \; 12 \frac{in}{ft} = 40.7 \text{ Inches } H_2O$$

The total pressure ΔP for the system is expected to be about 3 inches of water which is well below the 40.7 inches of the upper limit for the Darcy equation and therefore the Darcy equation will be used.

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JOB PM-2A Half Tank Air Flow
SHEET NO. 2 OF
CALCULATED BY Lowell DATE 7/8/03
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SCALE

Calculate the Reynolds number for the 10" air duct

$$\text{hydraulic radius} = \frac{\text{area of flow}}{\text{wetted perimeter}} = \frac{\pi D^2}{4} \Big/ \pi D = \frac{D}{4}$$

$$\text{equivalent diameter} = 4 \times \text{hydraulic radius} = 4 \times \frac{D}{4} = D$$

$D = 10/12 = 0.833$ ft. $d = 10''$

Page 3-2

$A = \pi D^2/4 = \frac{\pi (0.833)^2}{4} = 0.545 \text{ ft}^2$

$R_e = \frac{123.9\, d v \rho}{\mu}$

v = mean velocity in feet per second.

$$v = 1350 \frac{\text{ft}^3}{\text{min}} \cdot \frac{1}{0.545 \text{ ft}^2} \cdot \frac{\text{min}}{60 \text{ sec}} = 41.28 \text{ ft/sec}$$

ρ = weight density, lbs/ft^3

$= 0.07528$ lb/ft^3

μ = absolute viscosity in centipoise

Page A-5

$\mu = 0.018$ centipoise

$$R_e = \frac{(123.9)(10)(41.28)(0.07528)}{.018} = 2.139 \times 10^5$$

From Chart A-24 and a relative roughness $\epsilon/D = .001$

$f = 0.021$

$\frac{\text{ft}^2}{\text{sec}^2}\,\frac{\text{sec}^2}{\text{ft}} = \text{ft}$

For 100 ft of duct

$$h \text{ (feet of air)} = \frac{fL}{D}\frac{V^2}{2g_c} = \frac{(0.021)(100)}{0.833}\,\frac{(41.28)^2}{(2)(32.2)} = 66.71 \text{ ft air}$$

$$\Delta P = h\rho = 66.71 \text{ ft } 0.07528 \frac{\text{lb}}{\text{ft}^3} = 5.02 \text{ lb/ft}^2$$

$$h\text{(feet of water)} = \frac{\Delta P}{\rho_w} = 5.02 \frac{\text{lb}}{\text{ft}^2}\,\frac{\text{ft}^3}{62.4 \text{ lb}} = .080 \text{ ft}_{H_2O}$$

h(inches of water) $= .080 \times 12 = 0.965$ inches water per 100' duct.

h(inches of water per foot of duct) $= 0.010$ inches.

D PRODUCT 207

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JOB PM-2A Half Tank Air Flow
SHEET NO. 3 OF
CALCULATED BY Lowell DATE 7/9/03
CHECKED BY DATE
SCALE

Determine Equivalent Length. Charts A-26 and A-27

Entrance from half tank to duct.	$K = 0.50$
Exit duct to atmosphere	$K = 1.00$
Total	$= 1.50$

$$K = \frac{fL}{D} \qquad L = \frac{KD}{f}$$

$$L = \frac{(1.5)(0.833)}{.021} = 59.5 \text{ ft.}$$

Use 2 90° bends at r/d = 4. Use bend resistance.
Resistance due to length is included in duct length
L/D per bend = 8 for 2 bends L/D = 16

$$L = (16)(0.833) = 13 \text{ ft.}$$

Total length.

Duct from tank to filter	30'
Duct from filter to pump	3
Duct from pump to atmosphere	6
Entrance + Exit	60'
Duct bends	13'
Total equivalent length	112'

Total head (without filter) = (0.010)(112) = 1.1 inch H_2O.
0.010 inches H_2O head loss per equivalent foot of pipe from sheet 2

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JOB: PM-2A Hot Tank A - Flow
SHEET NO. 4. OF
CALCULATED BY: Lowell DATE: 7/9/03
CHECKED BY: DATE:
SCALE:

The axial flow fan will develope 3" head at 1350 cfm. The filter is rated at 1500 cfm with 1.3 inches water head loss. For 1350 cfm the head loss would be

$$h_{filter} = \left(\frac{1350}{1500}\right)^2 1.3 \approx 1.1 \text{ inches water.}$$

Head loss available for the filter is $h = 3 - 1.1 = 1.9$ inches.

The system will provide 1350 cfm for upto a $(1.9-1.1)/(1.1) = 73\%$ increase in filter head loss. The characteristic of the axial fan is that the developed head remains about 3" H_2O for a considerable range of flow below 1,350 cfm. The head loss of the ducts and entrance and exit losses varies as the square of the flow rate. If the filter resistance increases as particles are filtered out the flow will decrease, and head loss of the duct will decrease. If the flow were to decrease to 1,000 cfm the duct head loss would be

$$h_{1000\ cfm} = (1.1)\left(\frac{1000}{1350}\right)^2 = 0.604 \text{ " } H_2O$$

and $3 - 0.6 = 2.4$ inches H_2O would be available for the filter. 1000 cfm would still provide good positive flow therefore the filters in the filter housing would not need to be replaced until the filter head loss increases to

$$\% \text{ Increase} = \frac{2.4 - 1.1}{1.1} = 118\%$$

The system will provide good positive flow even with a large increase in filter resistance and is an adequate design.

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JOB PM-2A Hold Tank Air Flow
SHEET NO. 5 OF
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SCALE

As a rough check of line loss use Simplified Flow Formula for Compressible Fluids Page 3-22 Crane.

The pressure drop per 100 feet of pipe.

For flow of 1,350 cfm $\rho = .07528 \text{ lb/ft}^3$ Page A-8

$$W = 1{,}350 \frac{ft^3}{\cancel{min}} \; .07528 \frac{lb}{\cancel{ft^3}} \; 60 \frac{\cancel{min}}{hr}$$

$= 6{,}098 \text{ lb/hr}$

$= 6.098$ thousands of pounds per hr

$C_1 = 0.037$ Chart Page 3-22

For 10" schedule 20 (Approximation for flexible duct)

$C_2 = 0.0397$ Table Page 3-23

$$\Delta P_{100} = \frac{C_1 C_2}{\rho} = \frac{(0.037)(0.0397)}{.07528} = 0.020 \text{ psi}$$

$$h = 0.020 \frac{\cancel{lb}}{\cancel{in^2}} \; \frac{144 \cancel{in^2}}{1 \; ft^2} \; \frac{1 \; ft^3}{62.4 \cancel{lb}} = 0.046 \text{ ft water}$$

Δh inches of water $= .046 \times 12 = 0.552$ inches water, per 100 ft of pipe.

Calculation using Darcy equation is 0.965 inches water per 100 ft of pipe

The Darcy equation clearly gives conservative results and results of the Darcy Equation analysis will be used to justify design.

CRANE FLOW OF FLUIDS EQUATIONS AND CHARTS

Nomenclature

Unless otherwise stated, all symbols used in this book are defined as follows:

A = cross sectional area of pipe or orifice, in square feet

a = cross sectional area of pipe or orifice, in square inches

B = rate of flow in barrels (42 gallons) per hour

C = flow coefficient for orifices and nozzles = discharge coefficient corrected for velocity of approach = $C_d / \sqrt{1-(d_0/d_1)^4}$

C_d = discharge coefficient for orifices and nozzles

C_v = flow coefficient for valves; expresses flow rate in gallons per minute of 60 F water with 1.0 psi pressure drop across valve = $Q\sqrt{\rho/(62.4\Delta P)}$

D = internal diameter of pipe, in feet

d = internal diameter of pipe, in inches

e = base of natural logarithm = 2.718

f = friction factor in formula $h_L = fLv^2/D\,2g$

g = acceleration of gravity = 32.2 feet per second per second

H = total head, in feet of fluid

h = static pressure head existing at a point, in feet of fluid

h_g = total heat of steam, in Btu per pound

h_L = loss of static pressure head due to fluid flow, in feet of fluid

h_w = static pressure head, in inches of water

K = resistance coefficient or velocity head loss in the formula, $h_L = Kv^2/2g$

k = ratio of specific heat at constant pressure to specific heat at constant volume = c_p/c_v

L = length of pipe, in feet

L/D = equivalent length of a resistance to flow, in pipe diameters

L_m = length of pipe, in miles

M = molecular weight

MR = universal gas constant = 1544

n = exponent in equation for polytropic change ($p'V_a^n$ = constant)

P = pressure, in pounds per square inch gauge

P' = pressure, pounds per square inch absolute
(see page 1-5 for diagram showing relationship between gauge and absolute pressure)

p' = pressure, in pounds per square foot absolute

Q = rate of flow, in gallons per minute

q = rate of flow, in cubic feet per second at flowing conditions

q' = rate of flow, in cubic feet per second at standard conditions (14.7 psia and 60F)

q'_d = rate of flow, in millions of standard cubic feet per day, MMscfd

q'_h = rate of flow, in cubic feet per hour at standard conditions (14.7 psia and 60F), scfh

q_m = rate of flow, in cubic feet per minute at flowing conditions

q'_m = rate of flow, in cubic feet per minute at std. conditions (14.7 psia and 60F), scfm

R = individual gas constant = MR/M = $1544/M$

R_e = Reynolds number

r_c = critical pressure ratio for compressible flow

S = specific gravity of liquids relative to water, both at standard temperature (60 F)

S_g = specific gravity of a gas relative to air = the ratio of the molecular weight of the gas to that of air

T = absolute temperature, in degrees Rankine ($460 + t$)

t = temperature, in degrees Fahrenheit

$\overline{V}$ = specific volume of fluid, in cubic feet per pound

V = mean velocity of flow, in feet per minute

V_a = volume, in cubic feet

v = mean velocity of flow, in feet per second

v_s = sonic (or critical) velocity of flow of a gas, in feet per second

W = rate of flow, in pounds per hour

w = rate of flow, in pounds per second

w_a = weight, in pounds

x = percent quality of steam = 100 minus per cent of moisture

Y = net expansion factor for compressible flow through orifices, nozzles, or pipe

Z = potential head or elevation above reference level, in feet

Subscripts

(0) . . indicates orifice or nozzle conditions unless otherwise specified

(1) . . indicates inlet or upstream conditions unless otherwise specified

(2) . . indicates outlet or downstream conditions unless otherwise specified

(100) . refers to 100 feet of pipe

Greek Letters

Delta

Δ = differential between two points

Epsilon

ϵ = absolute roughness or effective height of pipe wall irregularities, in feet

Rho

ρ = weight density of fluid, pounds per cubic ft

ρ' = density of fluid, grams per cubic centimeter

Mu

μ = absolute (dynamic) viscosity, in centipoise

μ_e = absolute viscosity, in pound mass per foot second or poundal seconds per sq foot

μ'_e = absolute viscosity, in slugs per foot second or pound force seconds per square foot

Nu

ν = kinematic viscosity, in centistokes

ν' = kinematic viscosity, square feet per second

Darcy's Formula
General Equation for Flow of Fluids

Flow in pipe is always accompanied by friction of fluid particles rubbing against one another, and consequently, by loss of energy available for work; in other words, there must be a pressure drop in the direction of flow. If ordinary Bourdon tube pressure gauges were connected to a pipe containing a flowing fluid, as shown in Figure 1-6, gauge P_1 would indicate a higher static pressure than gauge P_2.

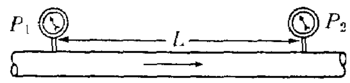


Figure 1-6

The general equation for pressure drop, known as Darcy's formula and expressed in feet of fluid, is $h_L = fLv^2/D\,2g$. This equation may be written to express pressure drop in pounds per square inch, by substitution of proper units, as follows:

$$\Delta P = \frac{\rho f L v^2}{144\, D\, 2g} \qquad \textit{Equation 1-4}$$

(For other forms of this equation, see page 3-2.)

The Darcy equation is valid for laminar or turbulent flow of any liquid in a pipe. However, when extreme velocities occurring in a pipe cause the downstream pressure to fall to the vapor pressure of the liquid, cavitation occurs and calculated flow rates will be inaccurate. With suitable restrictions, the Darcy equation may be used when gases and vapors (compressible fluids) are being handled. These restrictions are defined on page 1-7.

Equation 1-4 gives the loss in pressure due to friction and applies to pipe of constant diameter carrying fluids of reasonably constant weight density in straight pipe, whether horizontal, vertical, or sloping. For inclined pipe, vertical pipe, or pipe of varying diameter, the change in pressure due to changes in elevation, velocity, and weight density of the fluid must be made in accordance with Bernoulli's theorem (page 1-5). For an example using this theorem, see page 4-8.

Friction factor: The Darcy formula can be rationally derived by dimensional analysis, with the exception of the friction factor, f, which must be determined experimentally. The friction factor for laminar flow conditions ($R_e < 2000$) is a function of Reynolds number only; whereas, for turbulent flow ($R_e > 4000$), it is also a function of the character of the pipe wall.

A region known as the "critical zone" occurs between Reynolds number of approximately 2000 and 4000. In this region, the flow may be either laminar or turbulent depending upon several factors; these include changes in section or direction of flow and obstructions, such as valves, in the upstream piping. The friction factor in this region is indeterminate and has lower limits based on laminar flow and upper limits based on turbulent flow conditions.

At Reynolds numbers above approximately 4000, flow conditions again become more stable and definite friction factors can be established. This is important because it enables the engineer to determine the flow characteristics of any fluid flowing in a pipe, providing the viscosity and weight density at flowing conditions are known. For this reason, Equation 1-4 is recommended in preference to some of the commonly known empirical equations for the flow of water, oil, and other liquids, as well as for the flow of compressible fluids when restrictions previously mentioned are observed.

If the flow is laminar ($R_e < 2000$), the friction factor may be determined from the equation:

$$f = \frac{64}{R_e} = \frac{64\,\mu_e}{D\,v\rho} = \frac{64\,\mu}{124\,d\,v\rho}$$

If this quantity is substituted into Equation 1-4, the pressure drop in pounds per square inch is:

$$\Delta P = 0.000\,668\,\frac{\mu L v}{d^2} \qquad \textit{Equation 1-5}$$

which is Poiseuille's law for laminar flow.

When the flow is turbulent ($R_e > 4000$), the friction factor depends not only upon the Reynolds number but also upon the relative roughness, ϵ/D . . . . the roughness of the pipe walls (ϵ), as compared to the diameter of the pipe (D). For very smooth pipes such as drawn brass tubing and glass, the friction factor decreases more rapidly with increasing Reynolds number than for pipe with comparatively rough walls.

Since the character of the internal surface of commercial pipe is practically independent of the diameter, the roughness of the walls has a greater effect on the friction factor in the small sizes. Consequently, pipe of small diameter will approach the very rough condition and, in general, will have higher friction factors than large pipe of the same material.

The most useful and widely accepted data of friction factors for use with the Darcy formula have been presented by L. F. Moody[18] and are reproduced on pages A-23 to A-25. Professor Moody improved upon the well-established Pigott and Kemler[25, 26] friction factor diagram, incorporating more recent investigations and developments of many outstanding scientists.

The friction factor, f, is plotted on page A-24 on the basis of relative roughness obtained from the chart on page A-23 and the Reynolds number. The

Viscosity of Gases and Vapors

The curves for hydrocarbon vapors and natural gases in the chart at the upper right are taken from Maxwell[15]; the curves for all other gases in the chart are based upon Sutherland's formula, as follows:

$$\mu = \mu_0 \left(\frac{0.555\ T_0 + C}{0.555\ T + C}\right)\left(\frac{T}{T_0}\right)^{3/2}$$

where:

μ = viscosity, in centipoise at temperature T.

μ_0 = viscosity, in centipoise at temperature T_0.

T = absolute temperature, in degrees Rankine (460 + deg. F) for which viscosity is desired.

T_0 = absolute temperature, in degrees Rankine, for which viscosity is known.

C = Sutherland's constant.

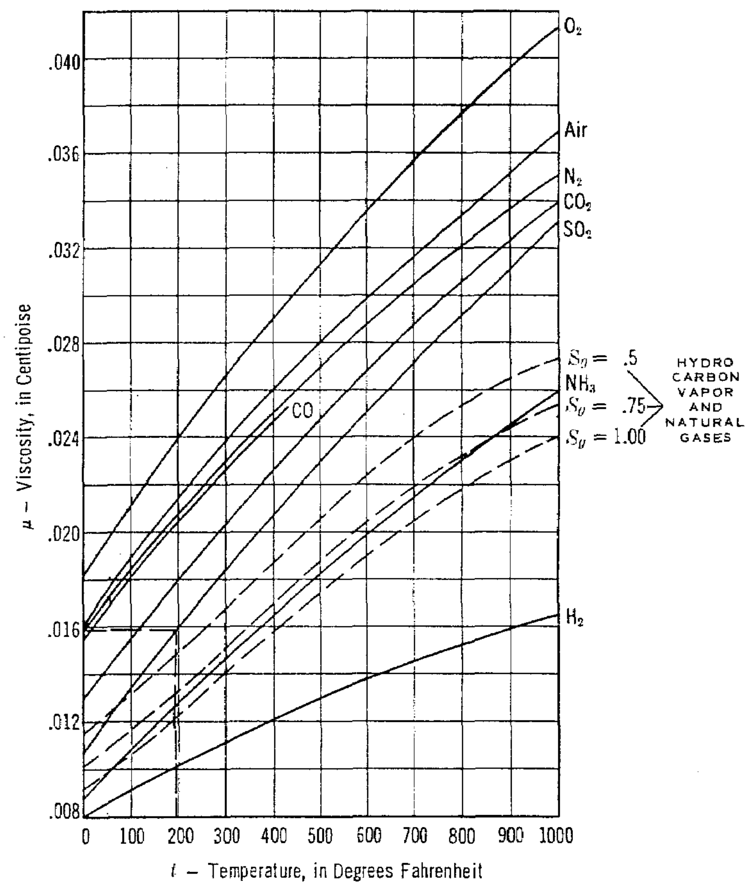
Note: The variation of viscosity with pressure is small for most gases. For gases given on this page, the correction of viscosity for pressure is less than 10 per cent for pressures up to 500 pounds per square inch.

Fluid	Approximate Values of "C"
O_2	127
Air	120
N_2	111
CO_2	240
CO	118
SO_2	416
NH_3	370
H_2	72

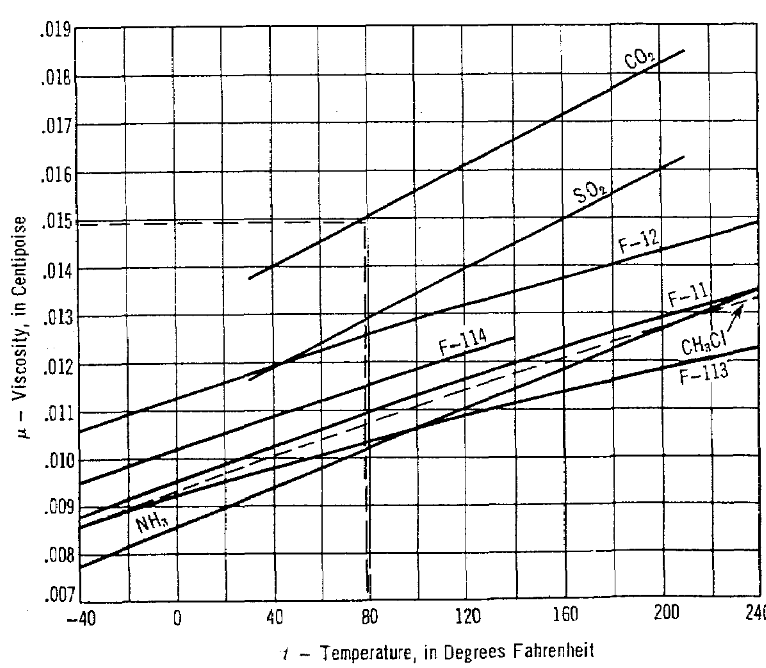
Upper chart example: The viscosity of sulphur dioxide gas (SO_2) at 200 F is 0.016 centipoise.

Lower chart example: The viscosity of carbon dioxide gas (CO_2) at about 80 F is 0.015 centipoise.

Viscosity of Various Gases



Viscosity of Refrigerant Vapors[11]
(saturated and superheated vapors)



Physical Properties of Gases[13]

c_p = specific heat at constant pressure
c_v = specific heat at constant volume

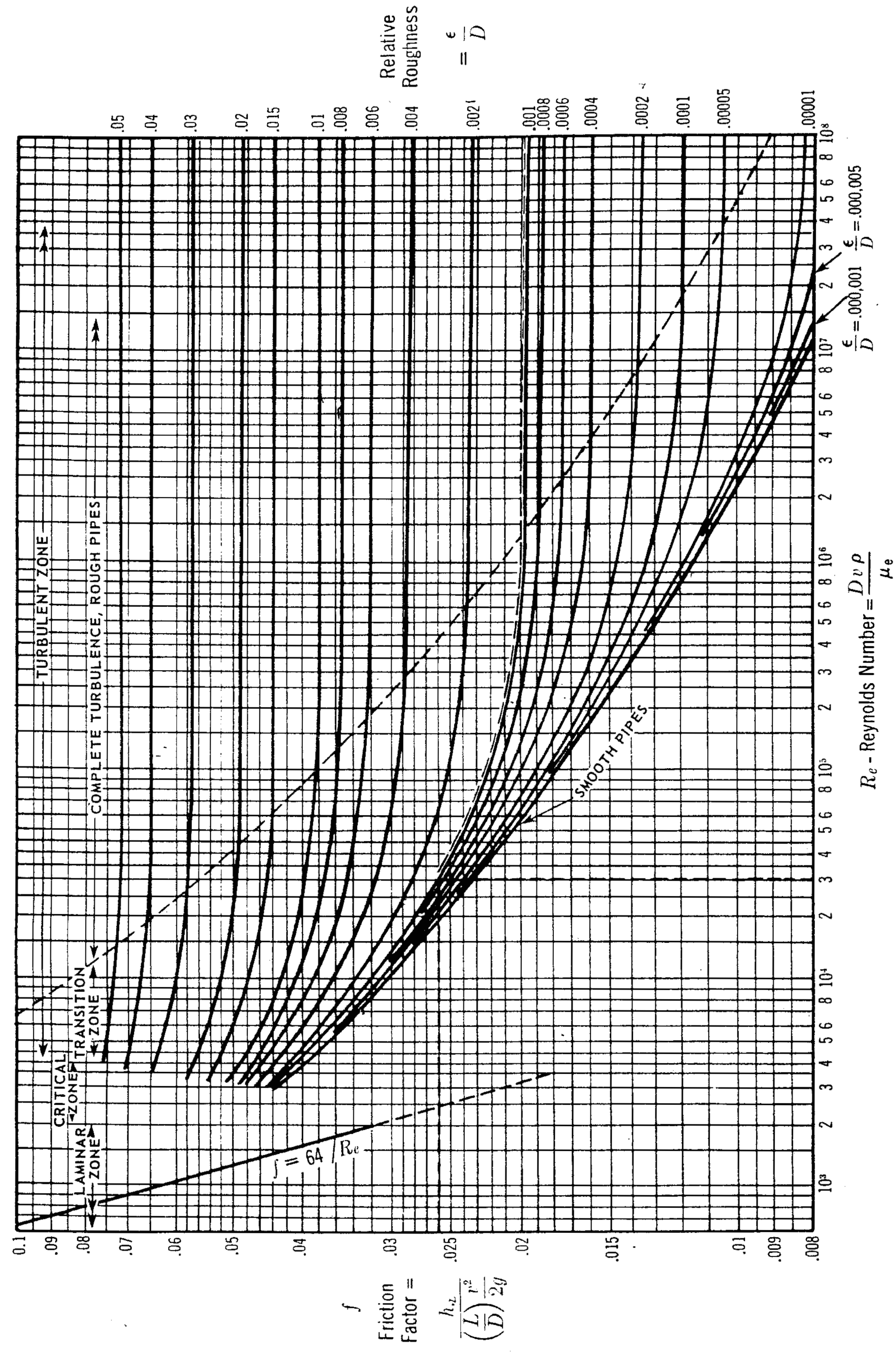
Name of Gas	Chemical Formula or Symbol	Approx. Molecular Weight M	Weight Density, Pounds per Cubic Foot* ρ	Specific Gravity Relative To Air S_g	Individual Gas Constant R	Specific Heat Per Pound at Room Temperature c_p	c_v	Heat Capacity Per Cubic Foot at Atmospheric Pressure and 68 F c_p	c_v	k equal to c_p/c_v
Acetylene	C_2H_2	26.0	.06754	.897	59.4	.350	.2737	.0236	.0185	1.28
Air	—	29.0	.07528	1.000	53.3	.241	.1725	.0181	.0130	1.40
Ammonia	NH_3	17.0	.04420	.587	90.8	.523	.4064	.0231	.0179	1.29
Argon	A	40.0	.1037	1.377	38.7	.124	.0743	.0129	.0077	1.67
Carbon Dioxide	CO_2	44.0	.1142	1.516	35.1	.205	.1599	.0234	.0183	1.28
Carbon Monoxide	CO	28.0	.07269	.965	55.2	.243	.1721	.0177	.0125	1.41
Ethylene	C_2H_4	28.0	.0728	.967	55.1	.40	.3292	.0291	.0240	1.22
Helium	He	4.0	.01039	.138	386.	1.25	.754	.0130	.0078	1.66
Hydrochloric Acid	HCl	36.5	.09460	1.256	42.4	.191	.1365	.0181	.0129	1.40
Hydrogen	H_2	2.0	.005234	.0695	767.	3.42	2.435	.0179	.0127	1.40
Methane	CH_4	16.0	.04163	.553	96.4	.593	.4692	.0247	.0195	1.26
Methyl Chloride	CH_3Cl	50.5	.1309	1.738	30.6	.24	.2006	.0314	.0263	1.20
Nitrogen	N_2	28.0	.07274	.966	55.2	.247	.1761	.0179	.0128	1.40
Nitric Oxide	NO	30.0	.07788	1.034	51.5	.231	.1648	.0180	.0128	1.40
Nitrous Oxide	N_2O	44.0	.1143	1.518	35.1	.221	.1759	.0253	.0201	1.26
Oxygen	O_2	32.0	.08305	1.103	48.3	.217	.1549	.0180	.0129	1.40
Sulphur Dioxide	SO_2	64.0	.1663	2.208	24.1	.154	.1230	.0256	.0204	1.25

*Weight density values are at atmospheric pressure and 68 F. For values at 60 F, multiply by 1.0154.

Volumetric Composition and Specific Gravity of Gaseous Fuels[13]

Type of Gas	Chemical Composition Percent by Volume: Hydrogen	Carbon Monoxide	Paraffin Hydrocarbons: Methane	Ethane	Illuminants: Ethylene	Benzene	Oxygen	Nitrogen	Carbon Dioxide	Specific Gravity Relative to Air S_g
Natural Gas, Pittsburgh	...	...	83.4	15.8	...	...	...	0.8	...	0.61
Producer Gas from Bituminous Coal	14.0	27.0	3.0	...	...	...	0.6	50.9	4.5	0.86
Blast Furnace Gas	1.0	27.5	...	...	...	...	...	60.0	11.5	1.02
Blue Water Gas from Coke	47.3	37.0	1.3	...	...	...	0.7	8.3	5.4	0.57
Carbureted Water Gas	40.5	34.0	10.2	...	6.1	2.8	0.5	2.9	3.0	0.63
Coal Gas (Cont. Vertical Retorts)	54.5	10.9	24.2	...	1.5	1.3	0.2	4.4	3.0	0.42
Coke-Oven Gas	46.5	6.3	32.1	...	3.5	0.5	0.8	8.1	2.2	0.44
Refinery Oil Gas (Vapor Phase)	13.1	1.2	23.3	21.7	39.6	...	1.0	...	0.1	0.89
Oil Gas, Pacific Coast	48.6	12.7	26.3	...	2.7	1.1	0.3	3.6	4.7	0.47

Friction Factors for Any Type of Commercial Pipe[18]



For other forms of the R_e equation, see page 3-2.

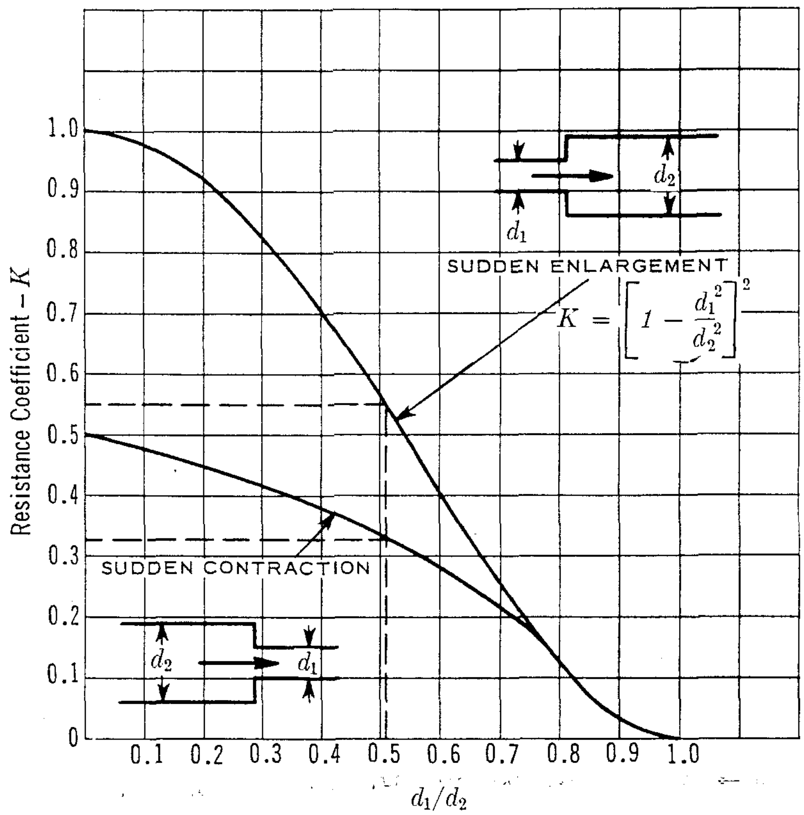
Data extracted from *Friction Factors for Pipe Flow* by L. F. Moody, with permission of the publisher, The American Society of Mechanical Engineers, 29 West 39th Street, New York 18, N. Y.

Problem: Determine the friction factor for 10-inch cast iron pipe (10.16″ I.D.) at a Reynolds number flow of 30,000.

Solution: The relative roughness (see page A-23) is 0.001. Then, the friction factor (f) equals 0.026.

Resistance in Pipe

Resistance Due to Sudden Enlargements and Contractions[20]



Sudden enlargement: The resistance coefficient K for a sudden enlargement from 6-inch Schedule 40 pipe to 12-inch Schedule 40 pipe is **0.55**, based on the 6-inch pipe size.

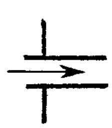
$$\frac{d_1}{d_2} = \frac{6.065}{11.938} = 0.51$$

Sudden contraction: The resistance coefficient K for a sudden contraction from 12-inch Schedule 40 pipe to 6-inch Schedule 40 pipe is **0.33**, based on the 6-inch pipe size.

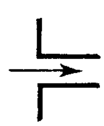
$$\frac{d_1}{d_2} = \frac{6.065}{11.938} = 0.51$$

Note: The values for the resistance coefficient, K, are based on velocity in the small pipe. To determine K values in terms of the greater diameter, multiply the chart values by $(d_2/d_1)^4$.

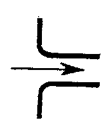
Resistance Due to Pipe Entrance and Exit



K = 0.78
Inward Projecting Pipe Entrance

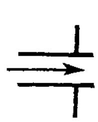


K = 0.50
Sharp Edged Entrance

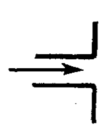


K = 0.23
Slightly Rounded Entrance

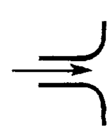
K = 0.04
Well Rounded Entrance



K = 1.0
Projecting Pipe Exit



K = 1.0
Sharp Edged Exit



K = 1.0
Rounded Exit

Problem: Determine the total resistance coefficient for a pipe one diameter long having a sharp edged entrance and a sharp edged exit.

Solution: The resistance of pipe one diameter long is small and can be neglected ($K = f\,L/D$).

From the diagrams, note:

Resistance for a sharp edged entrance	= 0.5
Resistance for a sharp edged exit	= 1.0

Then,

the total resistance, K, for the pipe	= **1.5**

Resistance of Bends

Resistance of 90 Degree Bends[21]

The chart at the right shows the resistance of 90 degree bends to the flow of fluids in terms of equivalent lengths of straight pipe.

Resistance of bends greater than 90 degrees is found using the formula:

$$\frac{L}{D} = R_t + (n-1)\left(R_l + \frac{R_b}{2}\right)$$

n = total number of 90° bends in coil
R_t = total resistance due to one 90° bend, in L/D
R_l = resistance due to length of one 90° bend, in L/D
R_b = bend resistance due to one 90° bend, in L/D

Problem: Determine the equivalent lengths in pipe diameters of a 90 degree bend and a 270 degree bend having a relative radius of 12.

Solution: Referring to the "Total Resistance" curve, the equivalent length for a 90 degree bend is **34.5** pipe diameters.

The equivalent length of a 270 degree bend is:

$$L/D = 34.5 + (3-1)\,[18.7 + (15.8 \div 2)]$$

$$L/D = \mathbf{87.7} \text{ pipe diameters}$$

Note: This loss is less than the sum of losses through three 90 degree bends separated by tangents. For "resistance of bends theory", see page 2-12.

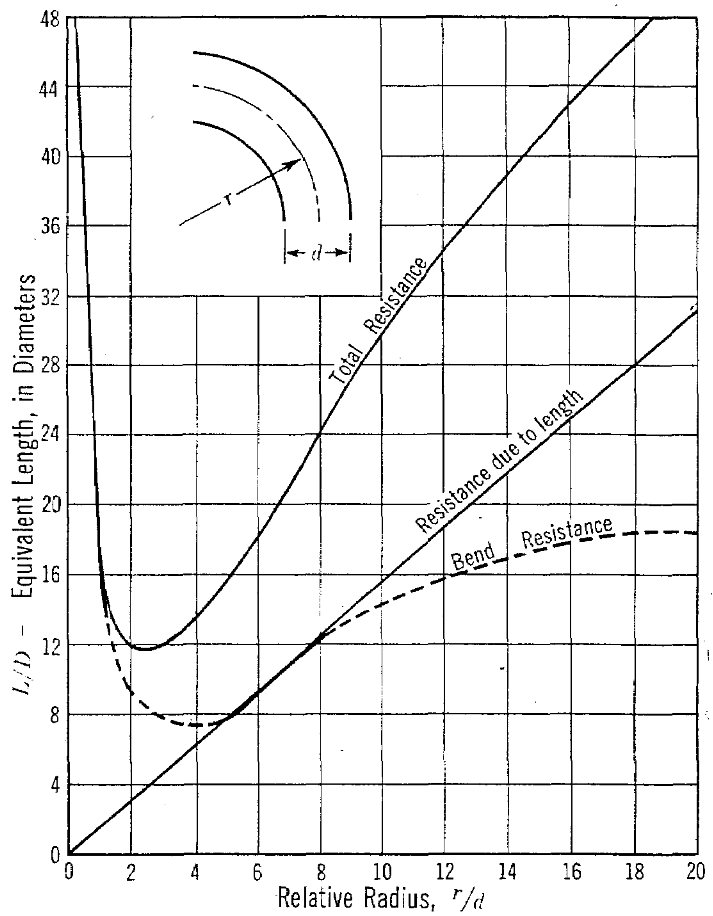


Chart for Resistance of 90 Degree Bends

From *Pressure Losses for Fluid Flow in 90 Degree Pipe Bends* by K. H. Beij. Courtesy of Journal of Research of National Bureau of Standards, Vol. 21, July, 1938.

Resistance of Miter Bends[4]

The chart at the lower right shows the resistance of miter bends to the flow of fluids. The chart is based on data published by the American Society of Mechanical Engineers (ASME).

Problem: Determine the equivalent length in pipe diameters of a 40 degree miter bend.

Solution: Referring to the "Total Resistance" curve in the chart, the equivalent length is **12** pipe diameters.

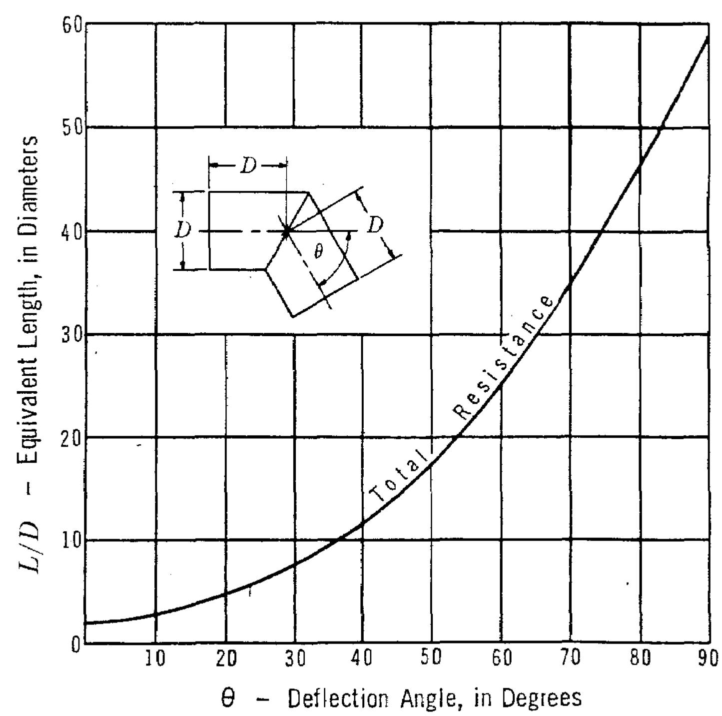


Chart for Resistance of Miter Bends